2020-FI-ENVECOPACK - Methodological report – February 2023

Developing pilot accounts for marine, freshwater and urban ecosystems and packaging materials

2020-FI-ENVECOPACK Deliverable D1.2

Hurskainen Pekka[1], Salminen Jani[1], Kopperoinen Leena[1], Saikkonen Liisa[1], Costadone Laura[1], Lai Tin-Yu[1], Lankia Tuija[2], Pokki Heidi[2], Husa Miikka[2], Johansson Annika[1], Jylhä Henna[1], Sorvari Jaana[1], Tikkanen Tommi[1], Heikinheimo Vuokko[1]

[1)] Finnish Environment Institute (Syke)
[2)] Natural Resources Institute Finland (Luke)

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1 Introduction

Finnish Environment Institute (Syke) and Natural Resources Institute Finland (Luke), the partners of the ENVECOPACK consortium, are national statistical organizations which report to Statistics Finland for provisioning of environmental and ecosystem accounts in Finland. The ENVECOPACK project, co-financed by Eurostat action grants for Environmental accounts and Ecosystem accounting, was led by Syke and implemented between March 2021 and February 2023.

The project focused at three themes within the statistical frameworks of environmental and ecosystem accounting and waste statistics. Firstly, we prototyped marine and freshwater ecosystem accounts with cultural and provisioning services for fishing. Second, we piloted urban green ecosystem accounting for Finnish municipalities, and third, we answered to the urgent need to have material-specific accounts on packaging materials and packaging waste.

The purpose of this report is to document the main outputs of the project. Emphasis is given to methodological development and technical description of the data and accounts. This report is structured to have independent sections for each work package (WP) and its theme. Large accounting tables, which could not be included in this report due to layout reasons, are disseminated as supplementary materials to this report.

2 Marine and freshwater ecosystem accounting for fishing (WP2)

Liisa Saikkonen[1], Tin-Yu Lai[1], Tuija Lankia[2], Miikka Husa[2], Heidi Pokki[2], Tommi Tikkanen[1]

[1] Finnish Environment Institute (Syke)

2 Natural Resources Institute Finland (Luke)

The work conducted in Work Package 2 (WP2) contributes to the development of ecosystem accounts for recreational and provisional ecosystem services from aquatic ecosystems.

2.1 Objectives

The overall objective of WP2 is to develop pilot marine and freshwater ecosystem services and asset accounts, covering recreational and provisional ES for fishing from marine and freshwater ecosystems, and further explore the approaches to integrate the EA results to the aquatic asset accounts under SEEA CF.

The stated specific objectives of WP2 are (from the project plan):

1. Quantifying and valuing recreational fishing in the marine and freshwater areas to pilot national supply and use accounts using regional data and models.
2. National pilot ES supply and use accounts related to fish from both marine and freshwater ecosystems for recreational and commercial fishing, in physical and monetary terms will be developed
3. The use of different valuation methods for developing monetary marine and freshwater ecosystem asset accounts for fish will be tested on national scale
4. Integration of marine and freshwater ES accounts into environmental accounts of SEEA CF and SNA is attempted to identify overlaps between different accounting frameworks and to assess the contributions of ecosystems to final products and services

2.2 Data Identification, collection and gaps

Table 1 includes the used information sources for data that can was used for compiling the supply, use and asset accounts for recreational and commercial fishing applying different valuation approaches. Information presented in the table is for the data of year 2018.

Table 1. Identified data sources for year 2018.

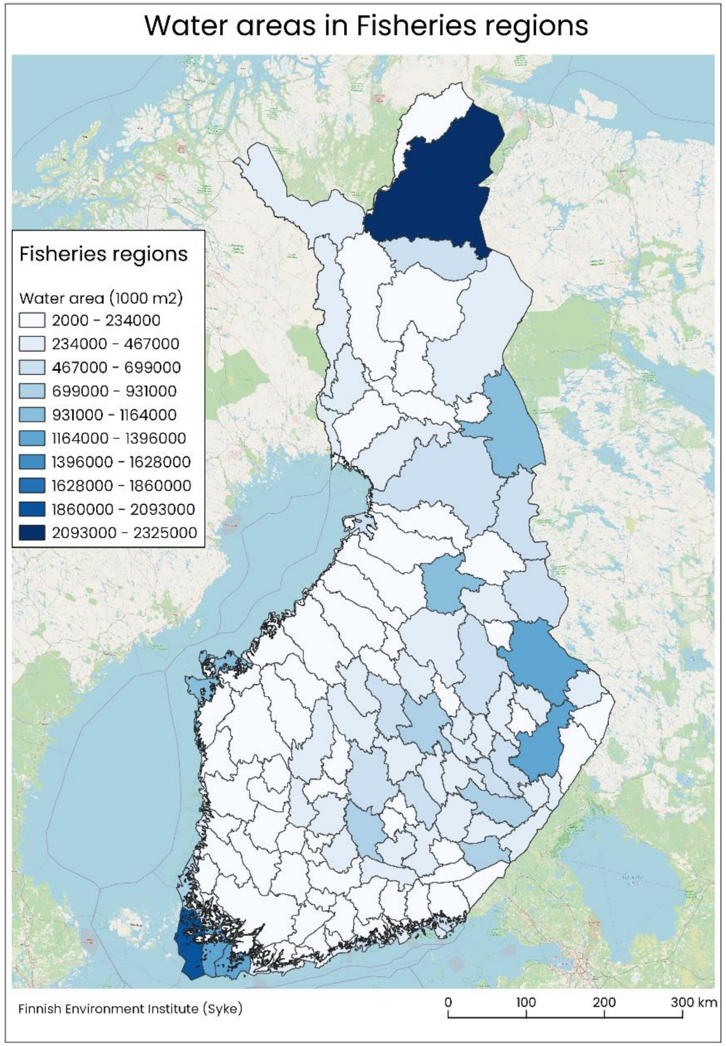
Account	Data	Data source(s)
Recreational supply and use	Expenses related to recreational fishing	Data from survey targeted to recreational fishers who have paid the fishery management fee (Pellikka & Eskelinen 2019).
Recreational supply and use accounts	Collected fishery management fees	Parks and wildlife Finland (2018): Fisheries management fee register. Data from survey targeted to recreational fishers who have paid the fishery management fee (Eskelinen & Mikkola , 2019).
Recreational supply and use accounts	Number of recreational fishers	Official Statistics of Finland (OSF). (2019). Recreational fishing 2018 [e-publication]. Natural Resources Institute Finland. https://stat.luke.fi/en/recreational-fishing.
Recreational supply and use accounts	Recreational fish catches and values	Official Statistics of Finland (OSF). (2019). Recreational fishing 2018 [e-publication]. Natural Resources Institute Finland. https://stat.luke.fi/en/recreational-fishing.
Recreational supply and use accounts	Permit and management fees	Parks and wildlife Finland (2018): Fisheries management fee register. Data from survey targeted to recreational fishers who have paid the fishery management fee (Eskelinen, & Mikkola ,2019).
Recreational supply and use accounts	Use of management fees for fishery management	Fisheries management fee register (2018), Parks and wildlife Finland. Data from survey targeted to recreational fishers who have paid the fishery management fee (Eskelinen & Mikkola, 2019).
Recreational supply and use accounts	Coefficients for consumer surpluses and exchange value approach	Pokki et al. (2021) Pellikka et al. (2021)
Commercial supply and use accounts	Economic performance data of commercial marine fishing	Marine fishery financial statements data by LUKE in EconomyDoctor: https://portal.mtt.fi/portal/page/portal/economydoctor/marine_fishery/timeline/financial_statements/, Scientific, Technical and Economic Committee for Fisheries (STECF)
Commercial supply and use accounts	Economic performance data of commercial freshwater fishing	Luke (2021). National statistics provided by LUKE, Kalatalouden toimialakatsaus 2021.
Commercial supply and use accounts	Landing amount and value of marine fish landings	Official Statistics of Finland (OSF). (2021). Commercial marine fishery [e-publication]. Natural Resources Institute Finland. https://stat.luke.fi/en/commercial-marine-fishery.

Account	Data	Data source(s)
Commercial supply and use accounts	Landing amount and value of freshwater fish landings	Official Statistics of Finland (OSF). (2021). Commercial inland fishery [e-publication]. Natural Resources Institute Finland. https://stat.luke.fi/en/commercial-inland-fishery.
Asset account	Approaches and bioeconomic model for asset accounts.	Lai et al. (2021) Lai & Saikkonen (2020)
Asset account	Fish stocks	LUKE and ICES stock assessments
Extent and condition accounts	Areas of surface water types and their condition	SYKE & NLS (2021). Shoreline10 and River Network. https://ckan.ymparisto.fi/dataset/ranta10-rantaviiva-1-10-000 Syke & Ely-centers (2021). Water bodies according to Water Framework Directive. https://ckan.ymparisto.fi/dataset/vesipuitedirektiivin-mukaiset-vesimuodostumat
Institutional context	Ownership of water areas	SYKE, National land Survey of Finland (Maanmittauslaitos), Kiinteistöalueet (Property areas) 2022

2.3 Institutional context and Ecosystem extent and condition

In addition to quantification and valuation of recreational and commercial fishing, regional accounts were compiled for the extents and conditions of ecosystems providing the services. The extent was defined as the area of surface waters and the condition as the ecological status of surface waters following the water framework directive. These are presented for the fisheries regions of Finland in Figure 1. Fisheries regions are spatial units which function as co-operation bodies for owners and users of water areas.

In addition to extent and condition, data were compiled on the ownership of water areas (see Figure 2). In Finland the owners of water areas can be divided into three categories: 1) co-owners, are the most common owner type of water areas in Finland. For co-owned water areas, multiple economic units share the ownership of water area; 2) private owners, where owner constitutes of one economic unit. Private owners are often municipalities or cities; 3) Government or state. Most of the offshore open water areas and areas with a protection status are owned by the government/state of Finland. The ownership of water areas can affect the market conditions of ecosystem services as well as the use and value of services.



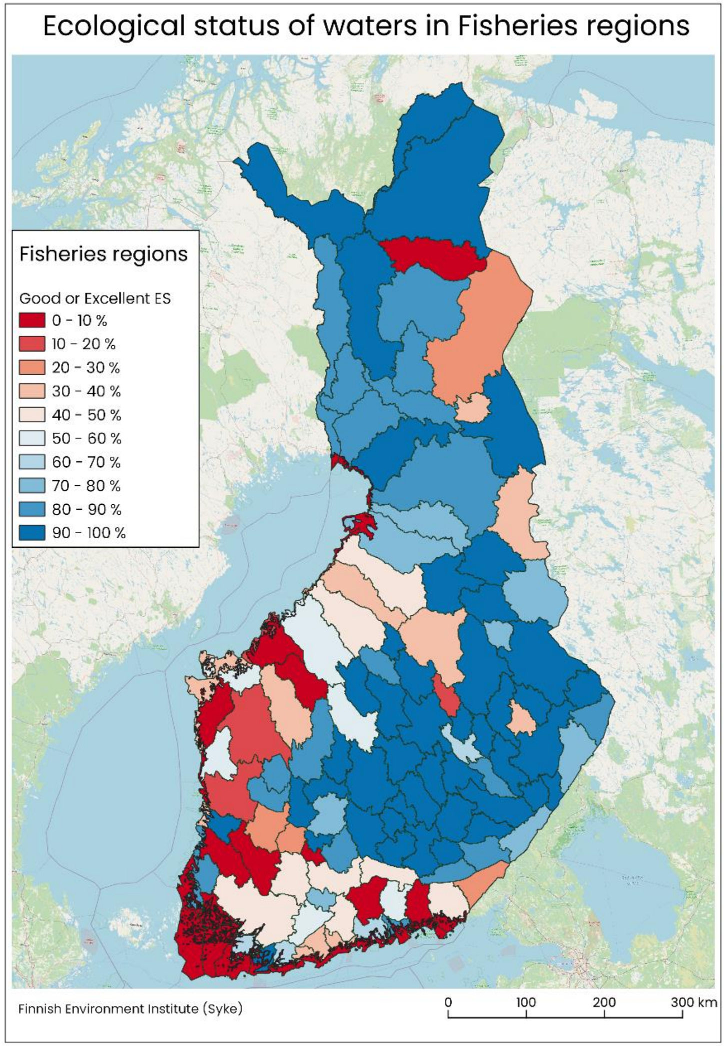
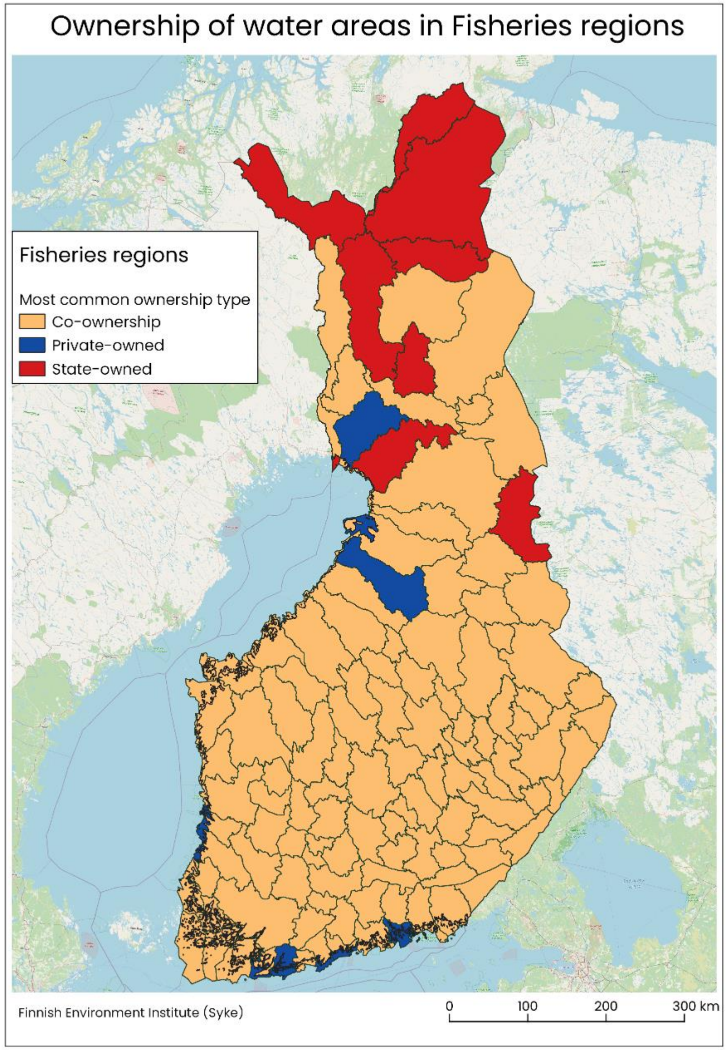


Figure 1. The extent of water ecosystems and condition of water ecosystems defined as the status of surface waters in fisheries regions



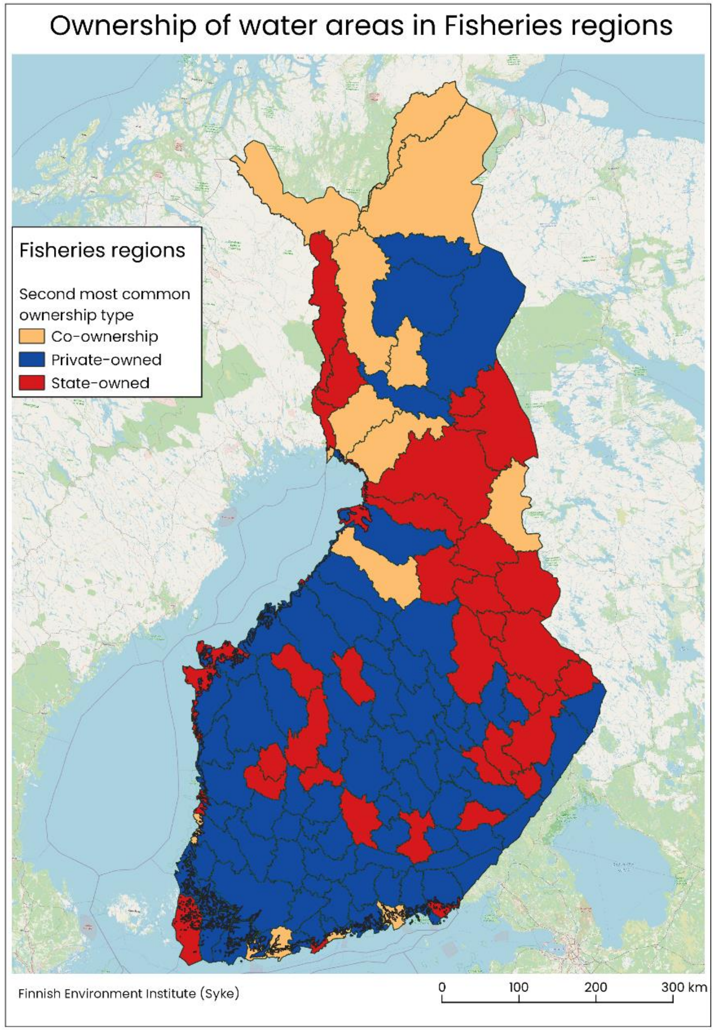


Figure 2. The most common ownership types of water areas in Fisheries regions.

2.4 **Quantifying and valuing recreational fishing**

2.4.1 Methods and data

2.4.1.1 **Methods for assessing the supply and use of the ecosystem services for recreational fishing in physical and monetary terms**

Although the recreational catches and sold fishing permits and fees are already included in the Finnish national accounts, these figures do not directly equal the contributions of ecosystems to the benefits resulting from recreational fishing. In this section the monetary value of the supply and use of the recreation fishing related ecosystem services is assessed with alternative methods following the SEEA EA recommended order of methods for valuing ecosystem services (UN 2021):

1) Methods where the price for the ecosystem service is directly observable:

- The stated fishing permit and management fee payments collected using a survey targeted to fishers who had paid the management fee.
- The total of collected fishery management fees allocated to fisheries regions and provinces based on surveyed number of fishing days.

2) Methods where the price for the ecosystem service is obtained from markets of similar goods and services:

- Quantity and value of fishing days that does not require payments based on a survey on recreational fishing activity of households.
- Value of fish catch for all fishers

3) Methods where the price for the ecosystem service is embodied in a market transaction:

- We argue that this method applies to the values defined using all other methods. None of the values defined by the other methods describe explicit payments for ecosystem service. For example, the revenue from fishery management fees is also used for administrative expenses and transaction costs.

4) Methods where the price for the ecosystem service is based on revealed expenditures for related goods and services

- Travel costs
- Other expenditures related to recreational fishing

5) Methods where the price for the ecosystem service is based on expected expenditures or markets:

- Simulated exchange value of fishery management fees, and how different market conditions affect supply, use and value of recreational fishing related ecosystem services.

The expenses paid for the right to fish, such as permits and management fees, can be interpreted as payments for the ecosystem services related to fishing. However, in Finland the payment of fisheries management fee allows the fishing in all provinces, and the fees are collected only from working age citizens who fish applying other methods than ice fishing, hook and line fishing with one rod or fishing with a simple herring rig. Fisheries management fee also permits lure fishing with one rod. Separate permit fees are further collected by the government or other water owners for fishing in certain areas and for the use of specific equipment. Data on the collected management fees is available from the fishery management fee register. In addition, data on the total number of fishing days requiring fishery management and/or permit fees paid per fisher have been collected by a survey (Eskelinen & Mikkola 2019). Here we provide estimates of the monetary value of the recreational fishing using both of these data sources as well as the recreational fishery statistics (OSF 2019) and related survey on the recreational fishing activity of households.

For comparison, the monetary value of recreational fishing is also estimated based on stated expenses and consumer surpluses of fishing days obtained from a travel cost model and related survey (Pokki et al. 2021; Pellikka et al. 2021). While the consumer surplus is commonly used to economic valuation of recreational use of nature in the environmental economics research, it should not be used to value the services for ecosystem accounting, since consumer surplus does not represent the exchange value of ecosystem service, but the utility/welfare that the consumer gains from using the service.

Finally, we assess the monetary value of recreational fishing with the simulated exchange value method (SEV) (Caparros et al. 2017) that has been suggested as method to derive the exchange value of non-market ecosystem services. The method builds on solving a hypothetical market equilibrium price for ecosystem services based on a demand curve for the ecosystem service derived using economic valuation method such as the travel cost method and the supply function of providing the service. In the application of SEV we apply the travel cost models by Pellikka et al. (2021) and Pokki et al. (2021) that provide demand curves for recreational fishing days. However, defining the supply curve is challenging, and our application is based on total collected fishery management fees and different assumptions on the functional form of the supply. As market conditions impact the equilibrium price, as well as the quantity and value of exchanged services, the SEV is estimated here using five different assumptions on the market conditions: 1) the current condition in which, according to fishing legislation, the fishery management fees cannot be sold for profit, but to cover the costs, 2) competitive market 3) monopoly, and 4) revenue maximization, assuming that the costs to supply the service are non-existent.

2.4.1.2 **Data and spatial units**

The main data sources for quantifying and valuing recreational fishing are:

i) survey targeted to recreational fishers who had paid the fishery management fee in 2018 on fishing days, fishing sites (**provinces**), fishing expenses, target species etc. (Pellikka & Eskelinen 2019 and Pellikka et al. 2021)

ii) survey targeted to recreational fishers who have paid the fishery management fee in 2017 or 2018 on fishing sites (**fisheries regions**), fishing days requiring management fees and/or additional permits etc. during 1.9.2017-31.8.2018 (Eskelinen & Mikkola 2019)

iii) recreational fishing statistics and related survey targeted to all households on the catch and fishing days in 2018 by **provinces** etc. (OSF 2019)

iv) Travel costs models for whole Finland and different **provinces** using the data of survey i). (Pokki et al. 2021 and Pellikka et al. 2021)

As can be seen from the list above, the data for the recreational fishing ecosystem service supply and use accounts have been collected using different spatial units and for slightly different time periods. This makes it more challenging to combine these data to compile the accounts on ecosystem service supply and use. We assume that the data of survey ii) for 1.9.2017-31.8.2018 represent the year 2018. Regarding the spatial aspects Table 2 shows the spatial units of different data that were used to compile the accounts. Maps of provinces, fisheries regions and their overlaps are presented in Figure 3.

Table 2. Data for 2018 for fishery management areas and provinces

Data	Fisheries regions	Provinces
Fishing days with fishery management fee	Survey ii)	-
Fishing days with fishing permits	Survey ii)	-
Collected fishery management fees, €	Fishery management fee register	
Recreational fish catch and value	-	Official Statistics of Finland (OSF) and survey iii).
Expenses	-	Survey i)
Number of visitors and average number of fishing days	-	Survey i)
Travel cost model for SEV	-	Survey i) and travel cost model iv)
Ownership of water areas	GIS data	GIS data
Areas of surface water types (rivers, lakes, coastal water)	GIS data	GIS data

The supply and use of the recreational fishing related ecosystem services in physical terms is estimated as the total number of fishing days in each province or fisheries regions. In the survey i), respondents reported their total number of fishing days in the last twelve months

(Pellikka & Eskelinen 2019). Average regional fishing days were calculated from respondents who only fished in one province. For the provincial data, if a fisher visited multiple (N) provinces then 1/N:th of fisher's all fishing days were allocated to each province to avoid overestimation of fishing days and their value. Whereas, in the survey ii) respondents reported their fishing days by fisheries regions, which consist of smaller areas than provinces that overlap and intersect with the provinces. The reported fishing days were either days that required the payment of fishery management fee or payment of both fishery management fee and additional permit fee (Eskelinen & Mikkola 2019). These data were used to calculate the number of these two fishing day types for each fisheries region. Due to different spatial units and discrepancies in deriving the regional or provincial values, the total number of fishing days requiring at least the payment of fishery management fee is different for provinces and fisheries regions.

To examine how data collected for different spatial units (fisheries regions and provinces) can be combined and compiled to form regional or provincial accounts, we use water area and fishery management fee days for allocation of provincial values to fisheries regions. The motivation to define spatially more disaggregated values from provinces to fisheries regions is to increase the policy relevancy of the ecosystem service accounts and to improve the linkages between the ecosystem service and ecosystem extent and condition accounts. Ecosystem extent accounts should be compiled from spatially exclusive ecosystem assets of the same habitat. Assets can supply ecosystem services for human use, and their supply potential is dependent on the condition of the assets and the ecosystem extents. The definition of ecosystem service supply and use accounts in the most disaggregated level as possible is the closest we get to linking the services and their value to the respective assets supplying them. Linking the ecosystem services to assets and their condition paves the way to analyses on for example how changes in environmental or fishery regulation can affect ecosystems and services at regional and spatially more aggregated levels.

Provincial data V_i was converted to regional data U_j by following formula:

$$U_j = \sum_{i \in J_j} \left(\frac{k_{ij}}{\sum_{j \in I_i} k_{ij}} \times V_i\right), \text{ where } k_{ij} = \frac{a_{ij}}{A_j} \times F_j \qquad (1)$$

Where:

a_{ij} is the water area of the overlap/intersection of province i and fisheries region j

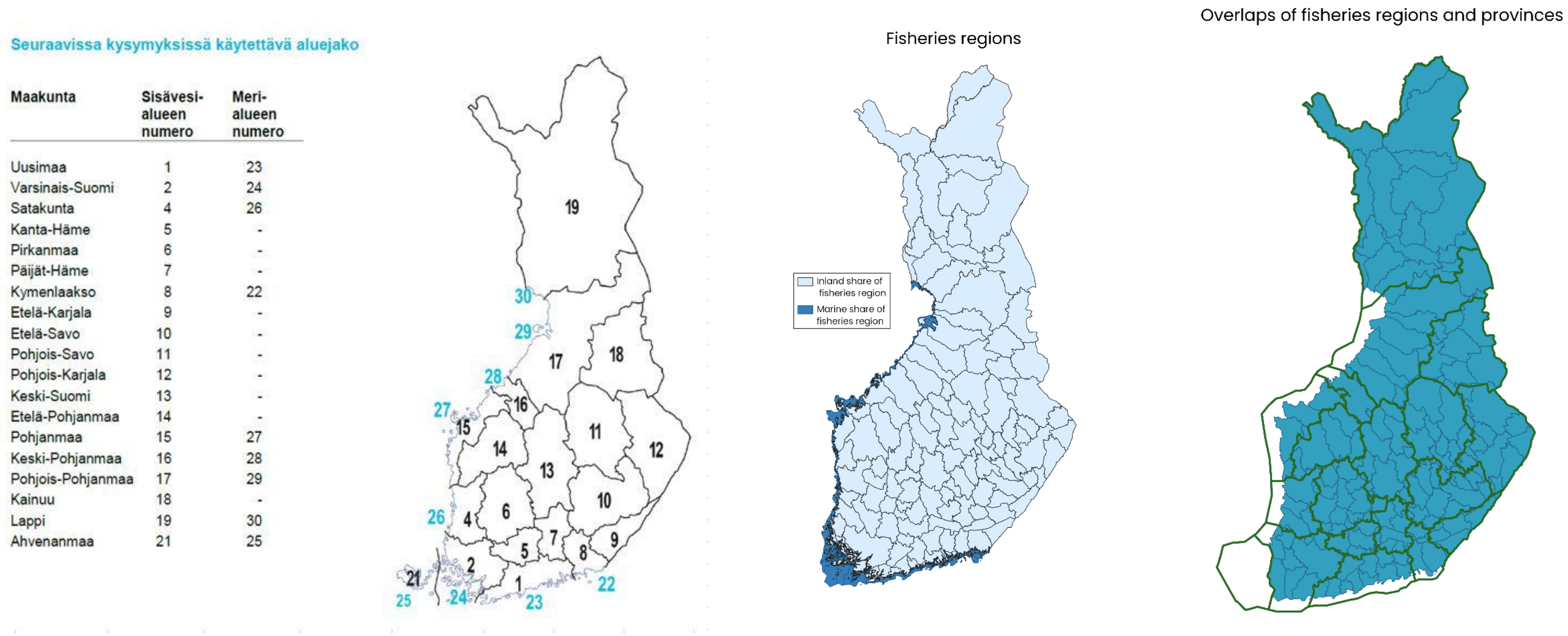
A_j is the total water area in fisheries region j

F_j is the number of fishery management fee fishing days in fisheries region j.

I_i includes all fisheries regions j that overlap with the province i

J_j includes all provinces i that overlap with the fisheries region j.

Formula (1) is used for all map results where provincial values are allocated to fisheries regions.



Seuraavissa kysymyksissä käytettävä aluejako

Maakunta	Sisävesi-alueen numero	Meri-alueen numero
Uusimaa	1	23
Varsinais-Suomi	2	24
Satakunta	4	26
Kanta-Häme	5	-
Pirkanmaa	6	-
Päijät-Häme	7	-
Kymenlaakso	8	22
Etelä-Karjala	9	-
Etelä-Savo	10	-
Pohjois-Savo	11	-
Pohjois-Karjala	12	-
Keski-Suomi	13	-
Etelä-Pohjanmaa	14	-
Pohjanmaa	15	27
Keski-Pohjanmaa	16	28
Pohjois-Pohjanmaa	17	29
Kainuu	18	-
Lappi	19	30
Ahvenanmaa	21	25

Figure 3 Provinces and marine areas of Finland.

2.4.2 Valuing recreational fishing for ecosystem service accounts

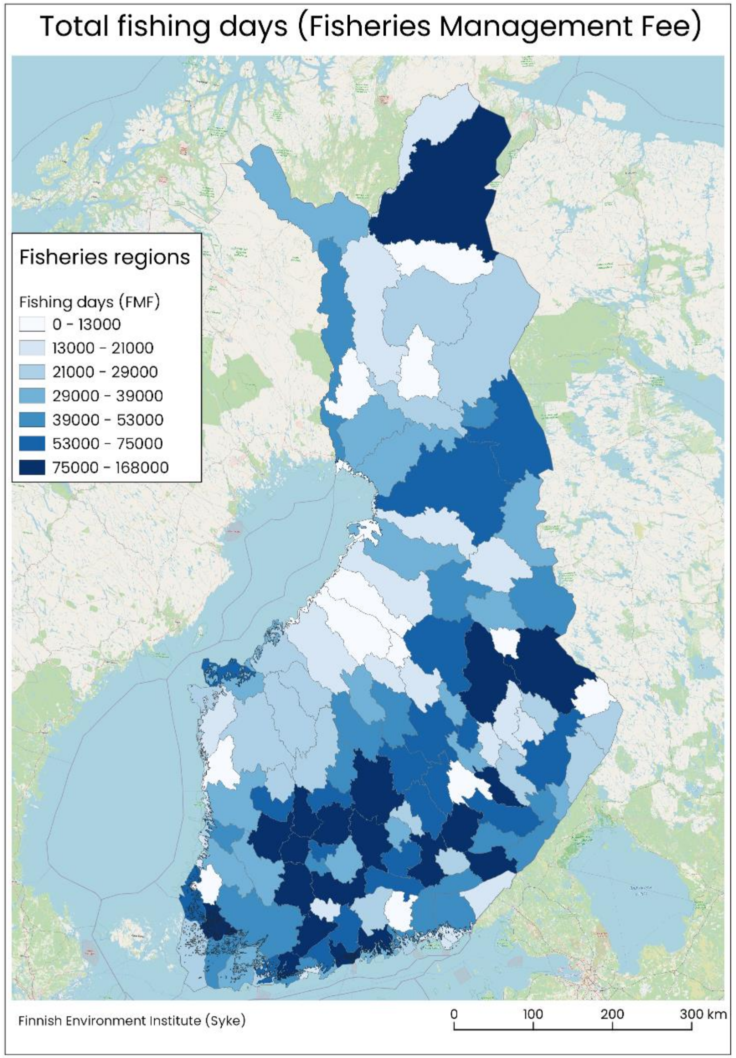
2.4.2.1 **Valuing recreational fishing using methods where the price for the ecosystem service is directly observable**

Table 3 presents supply and use of recreational fishing as fishing days and values of fishing days in different provinces of Finland (Figure 3) using the data collected by survey i) (Pellikka & Eskelinen, 2019 and Pellikka et al. 2021). The expenses paid for the right to fish, such as permits and management fees, can be interpreted as payments for the ecosystem services related to recreational fishing. According to the Table 2 it can be concluded that for most provinces the stated total of fishing permit and management fees exceed the collected management fees allocated to different provinces. In addition to estimating the monetary value of recreational fishing based on the fishery management and fishing permit fees, it was also defined as the consumer surplus per a fishing day. The total consumer surplus is over tenfold compared to the supply/use values based on permit and management fees for almost all provinces. However, consumer surplus should not be used to value the services for ecosystem accounting, since consumer surplus does not represent the exchange value of ecosystem service, but the utility/welfare that the consumer gains from using the service. The consumer surplus is based on a travel cost model (Pokki et al. 2021; Pellikka et al. 2021), where the stated combined costs of fishing permit and management fees were not found to have a statistically significant effect on the number of fishing days.

Figure 4 represents the fishery management fee fishing days for fisheries regions based on survey ii) (Eskelinen & Mikkola 2019), and allocation of total revenue from management fees using the fishery management fee fishing days for allocation. Figure 5 shows fishing days requiring payment of additional permit fee defined from survey ii) and permit fees defined as provincial fishery management fees deducted from total fishing permit and management fees of Table 2 distributed to fisheries regions using management fee days and shares of surface water areas.

Table 3. Monetary supply/use accounts based on observed ecosystem service market. Destination refers to the Finnish provinces, i.e. freshwater areas (1-21) and marine areas (22-30), as illustrated in Figure 3.

	Destination	Total fishing days	Total value of fishing permits and management fees €	Total value of fisheries management fees €)	Average consumer surplus €/day	Total consumer surplus €
1	Uusimaa	307 476	1 098 302	575 060	78	23 854 009
2	Varsinais-Suomi	148 020	429 639	262 771	78	11 483 389
4	Satakunta	84 412	341 787	155 522	78	6 548 658
5	Kanta-Häme	141 091	472 202	226 204	78	10 945 838
6	Pirkanmaa	324 902	836 969	614 466	36	11 729 317
7	Päijät-Häme	164 402	496 426	300 556	37	6 050 864
8	Kymenlaakso	144 730	666 576	240 851	57	8 237 335
9	Etelä-Karjala	181 632	473 787	264 308	66	11 925 936
10	Etelä-Savo	452 986	1 237 125	651 197	26	11 964 766
11	Pohjois-Savo	373 048	670 543	531 135	33	12 283 425
12	Pohjois-Karjala	331 603	1 084 621	523 679	34	11 150 051
13	Keski-Suomi	347 753	1 463 211	665 657	44	15 159 246
14	Etelä-Pohjanmaa	71 107	387 493	146 428	78	5 516 507
15	Pohjanmaa	42 642	125 305	86 898	34	1 459 346
16	Keski-Pohjanmaa	24 750	103 611	47 898	78	1 920 124
17	Pohjois-Pohjanmaa	230 957	999 744	470 981	39	9 042 934
18	Kainuu	153 849	594 038	257 040	45	6 892 887
19	Lappi	430 066	2 735 515	815 524	48	20 577 344
22	Kymenlaakso-Marine	49 747	64 331	68 347	121	6 029 971
23	Uusimaa-Marine	138 155	294 099	291 585	121	16 746 095
24	Varsinais-Suomi-Marine	173 779	330 281	278 643	73	12 656 916
26	Satakunta-Marine	43 212	160 020	65 011	121	5 237 869
27	Pohjanmaa-Marine	65 723	209 550	112 810	121	7 966 470
28	Keski-Pohjanmaa-Marine	26 051	86 988	28 695	121	3 157 680
29	Pohjois-Pohjanmaa-Marine	60 299	123 590	70 113	121	7 308 916
30	Lappi-Meri	5 730	90 335	14 193	121	694 526
	Finland total	4 518 122	15 576 088	7 765 572		246 540 419



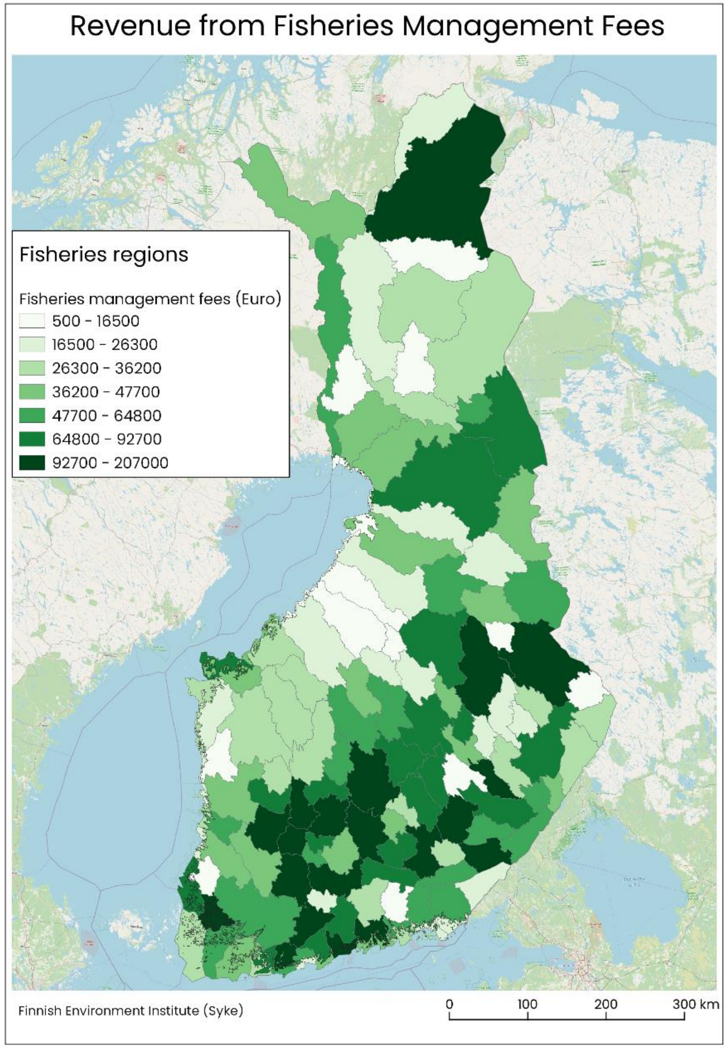
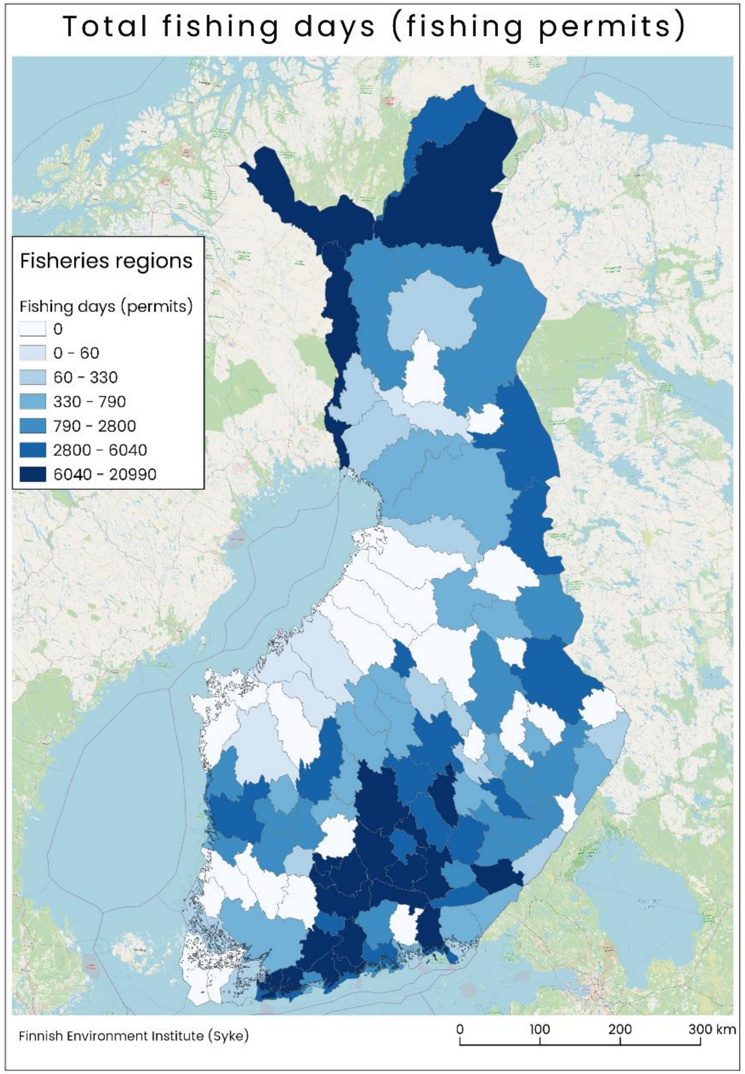


Figure 4. Fisheries management fees: number of fishing days and total revenue.



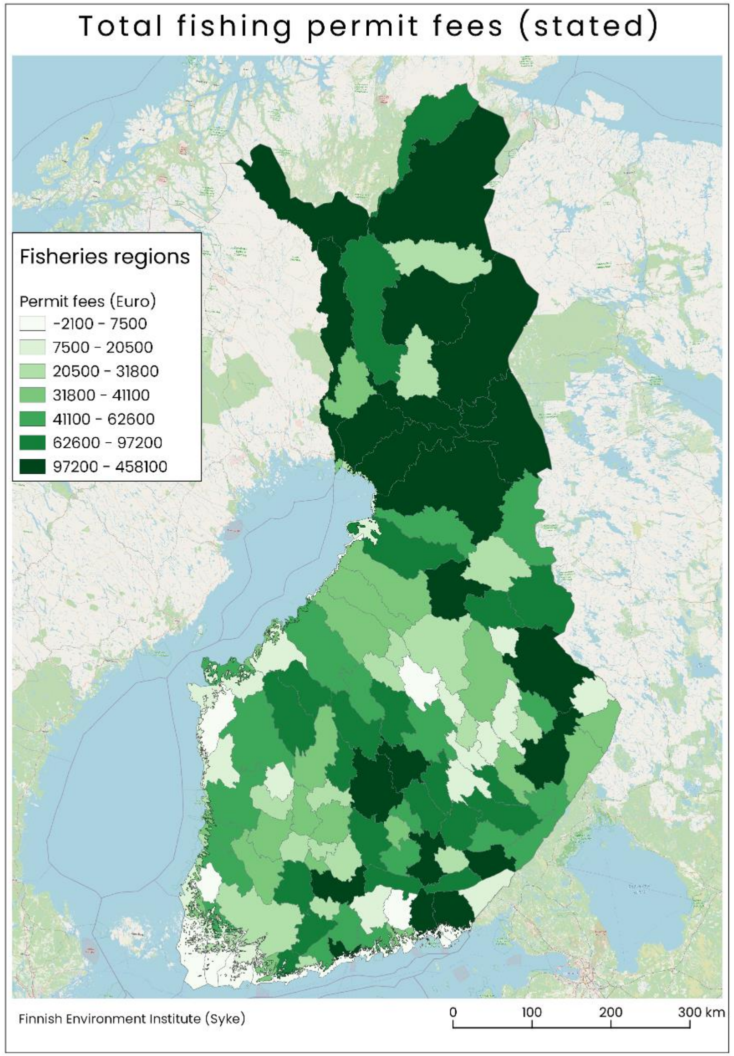


Figure 5. Fishing permits: number of fishing days and total fees

2.4.2.2 **Valuing recreational fishing using methods where the price for the ecosystem service is obtained from markets of similar goods and services**

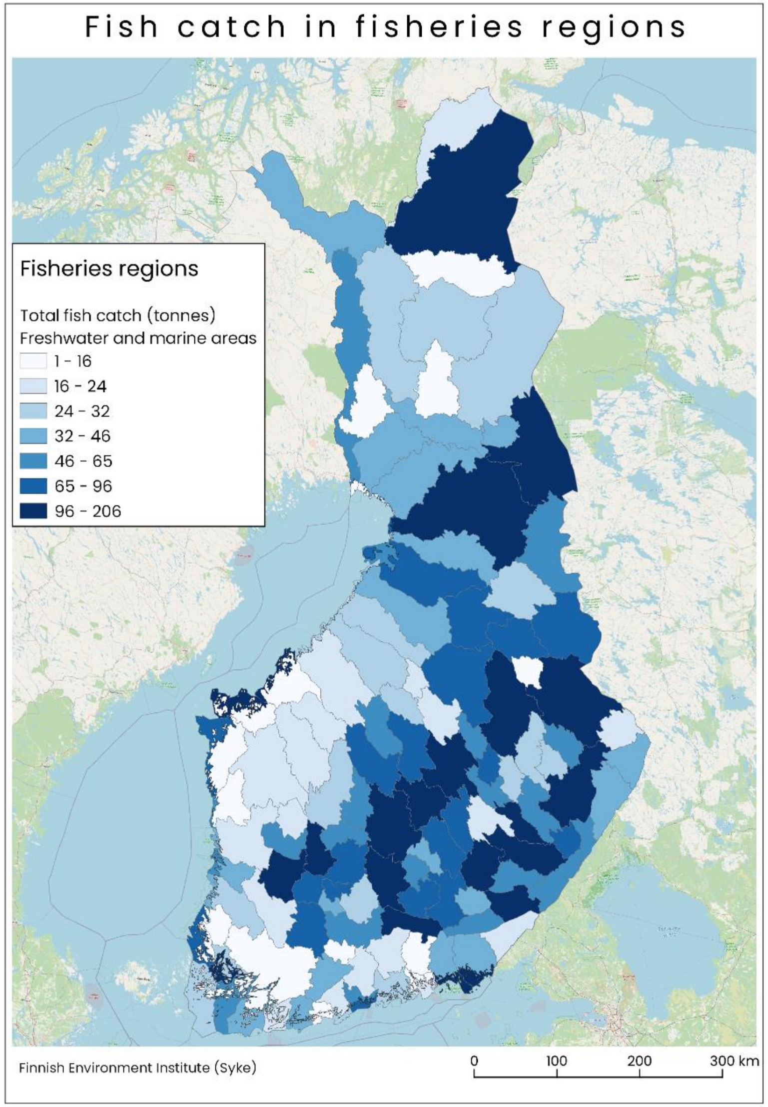
Table 4 presents the recreational fish catches for fishers who paid the management fees and for the fishers who did not pay the fisheries management fee. The recreational catches for both types of fishers are from the recreational fishery statistic (OSF 2019. However, the ecosystem's contribution to recreational fish catch cannot be considered as part of the recreational fishing related ecosystem service, since according to the SEEA EA (UN 2021), if the harvest from recreational fishing is retained for subsequent consumption, then the quantity of the associated biomass should be included as part of biomass provisioning services. The number of fishers who did not pay management fees is also from the recreational fishery statistic (OSF 2019). It was further estimated that the average fishing days per fisher for provinces are the same as for the fishers who paid the management fee, and thus their amount of fishing days presented in Table 4 may be overestimations.

Figure 6 and Figure 7 present the provincial catches and their values allocated to fisheries regions for fishers who paid fees and fishers who did not pay fees respectively. Figure 7 also shows the amount of fishing days and their values allocated to fisheries regions for fishers who did not pay the fishery management fee. The values were defined so that the value of one day (1.23 €) is the total value of collected fishery management fees divided by the total amount of fishery management fee days based on survey ii).

Table 4. The catches and their values for different types of fishers and quantity of recreational fishing for fishers who did not pay the management fee.

	Fishers who paid the management fee		Fishers who did not pay the management fee		
Destination	**Fish catch (tons)**	**Fish value (1000 €)**	**Fish catch (tons)**	**Fish value (1000 €)**	**Fishing days**
Uusimaa	251	703	278	779	1 117 329
Varsinais-Suomi	77	173	337	757	508 688
Satakunta	104	233	255	572	359 707
Kanta-Häme	126	404	779	2 500	514 333
Pirkanmaa	702	2 253	814	2 614	1 993 430
Päijät-Häme	355	1 139	335	1 074	699 335
Kymenlaakso	116	320	520	1 438	1 052 559
Etelä-Karjala	241	667	1 184	3 274	2 141 516
Etelä-Savo	789	2 029	800	2 058	2 096 253
Pohjois-Savo	548	1 433	873	2 283	2 500 979

	Fishers who paid the management fee		Fishers who did not pay the management fee		
Pohjois-Karjala	601	1 883	1 166	3 653	1 697 056
Keski-Suomi	674	2 224	1 180	3 895	1 730 469
Etelä-Pohjanmaa	69	165	404	966	681 855
Pohjanmaa	6	15	290	693	363 945
Keski-Pohjanmaa	28	67	27	64	155 379
Pohjois-Pohjanmaa	444	1 179	559	1 486	1 165 784
Kainuu	355	943	355	944	924 363
Lappi	510	1 551	1 971	5 995	1 999 061
Kymenlaakso-Marine	239	668	84	235	150 628
Uusimaa-Marine	223	853	481	1 836	939 980
Varsinais-Suomi-Marine	408	1 191	591	1 724	1 939 826
Satakunta-Marine	140	408	46	136	701 765
Pohjanmaa-Marine	455	1 145	406	1 023	461 109
Keski-Pohjanmaa-Marine	17	44	107	269	115 921
Pohjois-Pohjanmaa-Marine	273	670	193	474	405 464
Lappi-Meri	13	31	225	546	58 119
Total for Finland	7764	22391	14260	41288	21774239



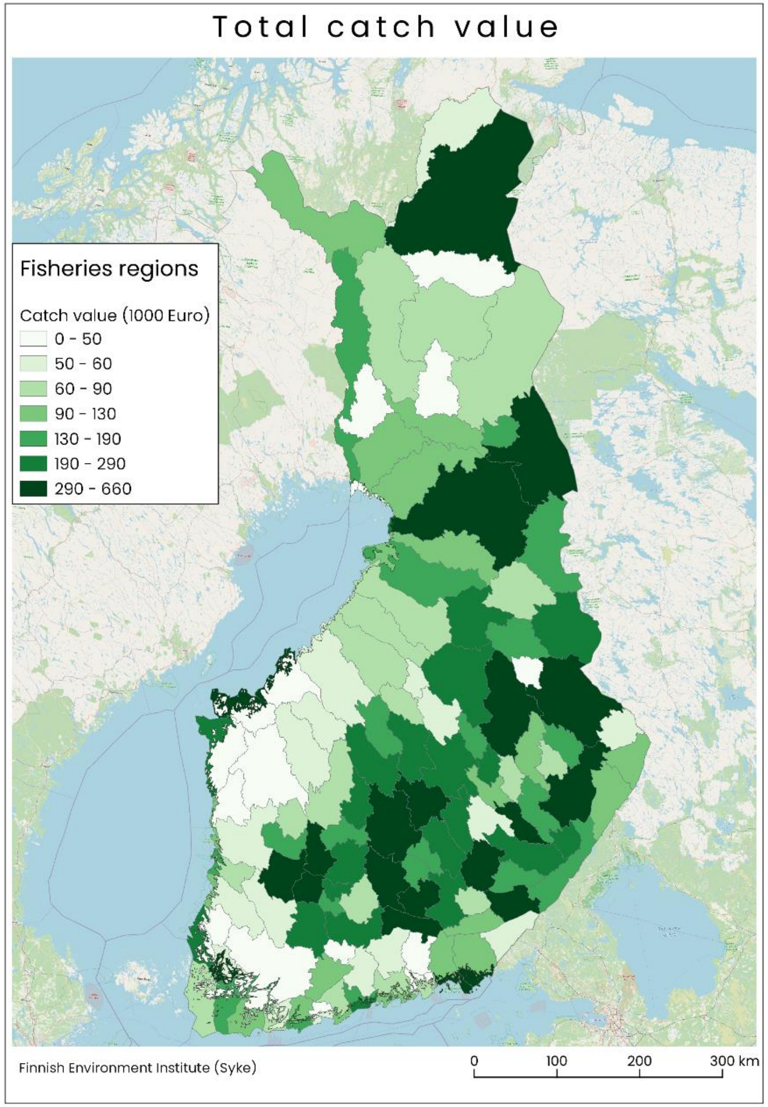


Figure 6. Fish catch and total catch value in Fisheries regions.

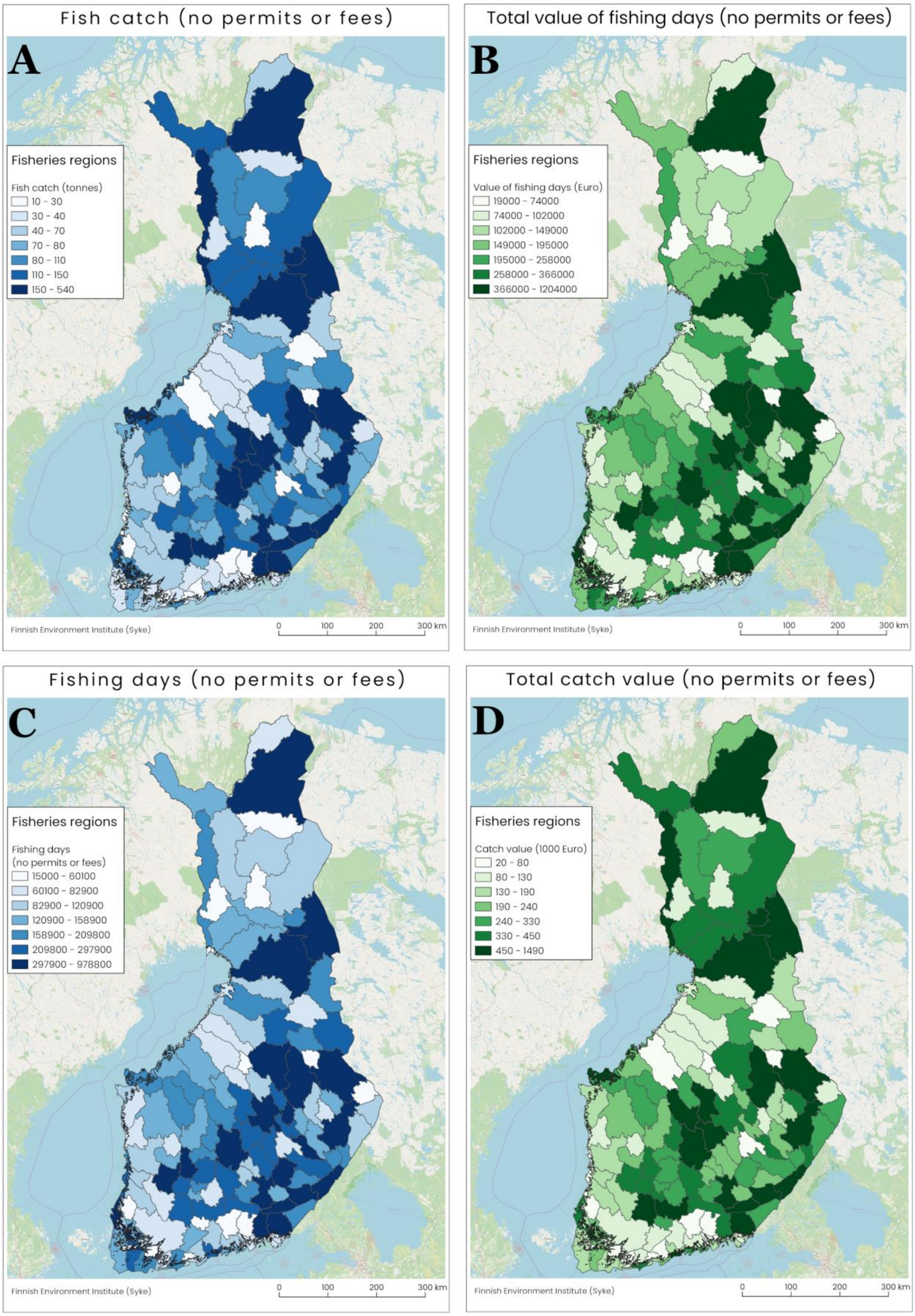


Figure 7. Fish catch (A) and total catch value (B) in Fisheries regions (No fishing permits or fisheries management fee required) and the amount of fishing days (C) and their values (D) allocated to fisheries regions for fishers who did not pay the fishery management fee.

2.4.2.3 **Valuing recreational fishing using methods where the price for the ecosystem service is embodied in a market transaction**

This valuation method type should likely be applied to all the values defined by other methods. The observed market prices for the exchange of ecosystem services or similar services usually include at least transaction and administration costs to provide access to the services. For example, the revenue from fishery management fees is used as described in Figure 8, where approximately 26% of the revenue from fishery management fees is used to cover the administration and transaction costs. Rest of the revenue is used for fishery management at different levels. Fishery management on the other hand can be considered as ecosystem maintenance and its costs as value of ecosystem services. This would mean that the values for recreational fishing related ecosystem service supply and use defined as value of fishery management fees (e.g. Table 3) should only include 74% of the management fee value. The same kind of treatment should likely be applied also to values defined based on the value of fishing permits. The value of recreational fish catch does not constitute only of the value of ecosystem's contribution, but of the value of other inputs such as fishing equipment, boat, fuel etc. Therefore, the costs of these inputs should be deducted from the value of fish catch to capture the value of the contribution of the ecosystem.

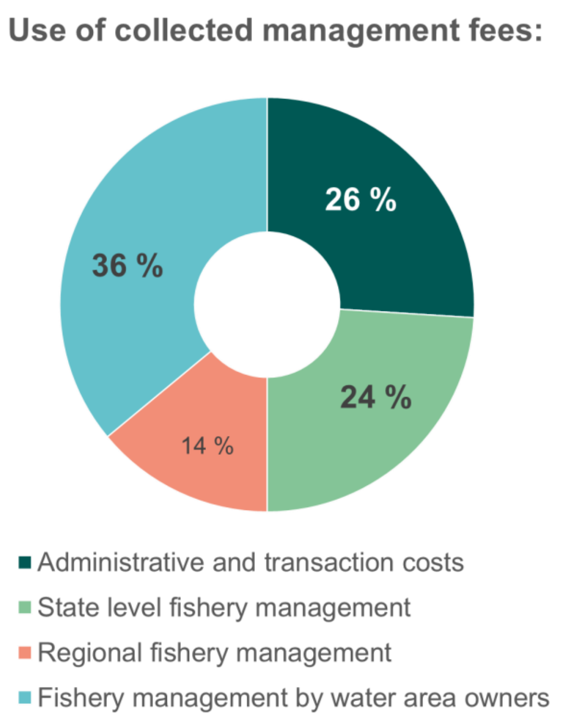


Figure 8. The use of revenue from the fishery management fees. Data from: Parks Wildlife Finland.

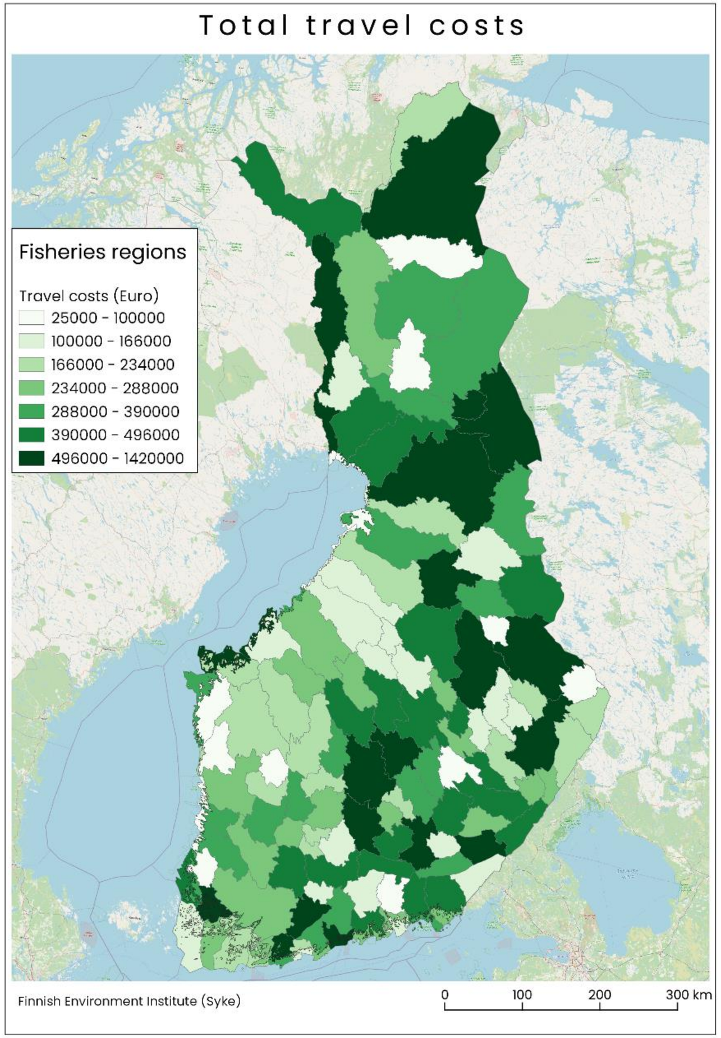
2.4.2.4 Valuing recreational fishing using methods where the price for the ecosystem service is based on revealed expenditures for related goods and services

Table 5 includes travel costs (without opportunity cost of time) and other expenses (accommodation, membership payments, program services and miscellaneous expenses) by provinces for the fishers who paid the fishery management fee based on survey i) Pellikka et al. (2021). According to this type of methods the value is defined following the *related expenditures approach*, where the costs to access and use the recreational service are used to value the service. Figure 9 illustrates these costs allocated to fisheries regions.

Table 5. Use accounts using related expenditures approach. Destination refers to the division of Finnish provinces, i.e. freshwater areas (1-21) and marine areas (22-30), as illustrated in Figure 1.

Destination	Total travel costs €	Total other expenses €
Uusimaa	4 122 104	1 225 330
Varsinais-Suomi	1 720 140	1 077 115
Satakunta	1 219 835	341 231
Kanta-Häme	1 118 399	512 818
Pirkanmaa	2 105 430	1 306 492
Päijät-Häme	1 526 668	413 840
Kymenlaakso	1 384 033	1 579 300
Etelä-Karjala	1 793 211	417 897
Etelä-Savo	2 888 459	1 440 886
Pohjois-Savo	2 741 802	1 316 177
Pohjois-Karjala	2 510 365	1 439 942
Keski-Suomi	3 759 515	1 319 734
Etelä-Pohjanmaa	774 263	245 271
Pohjanmaa	374 995	136 257
Keski-Pohjanmaa	314 996	94 019
Pohjois-Pohjanmaa	2 341 140	1 124 923
Kainuu	1 857 514	577 895
Lappi	5 952 519	3 762 930
Kymenlaakso-Marine	563 268	260 605
Uusimaa-Marine	1 927 979	415 006
Varsinais-Suomi-Marine	2 186 495	1 147 982

Destination	Total travel costs €	Total other expenses €
Satakunta-Marine	240 029	168 247
Pohjanmaa-Marine	2 009 098	415 997
Keski-Pohjanmaa-Marine	453 390	200 161
Pohjois-Pohjanmaa-Marine	327 223	403 491
Lappi-Meri	141 956	133 180
Total for Finland	46 354 826	21 476 726



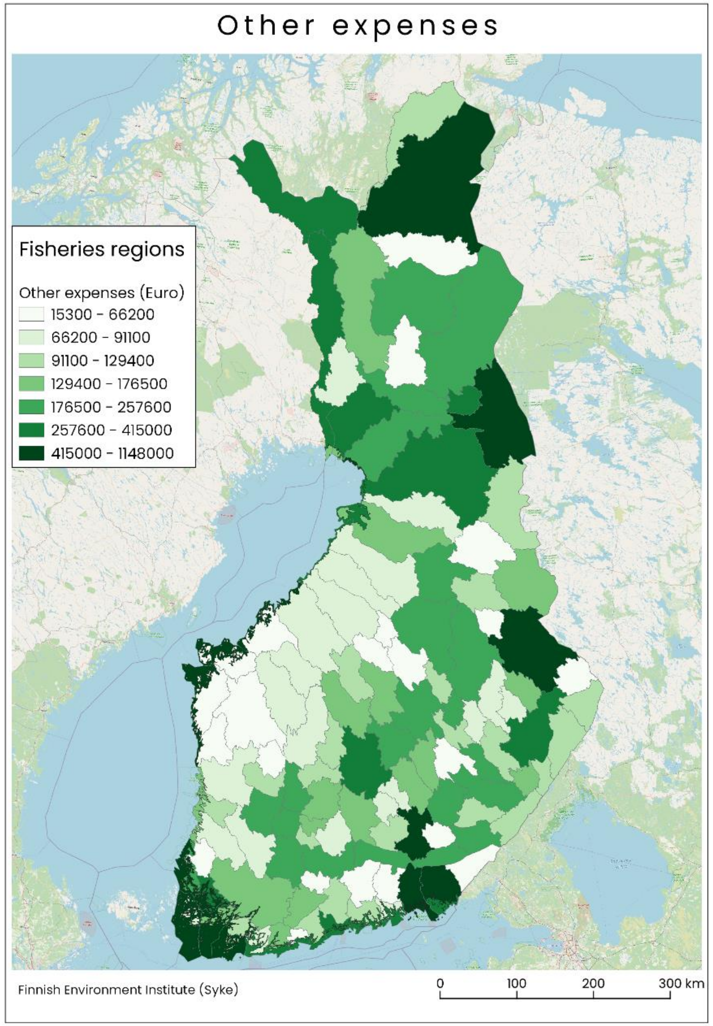


Figure 9. Travel costs and other expenses related to Fisheries management fees in Fisheries regions.

2.4.3 Application of simulated exchange value on recreational fishing

Exchange value of recreational fishing was simulated using a travel cost model by Pokki et al. (2021) and Pellikka et al. (2021) to define the demand function for recreational fishing days (see an example on outdoor recreational visits by Lankia et al. (2020). Since there already exists a market for recreational fishing, where fishery management fees and permit prices are paid for recreational fishing, we first calibrate the parameters for supply and use by simulating market for the actual exchange of fishery management fee fishing days. According to the Finnish law on fisheries, fishery management fees cannot be sold for profit, but to cover the costs of providing the access to recreational fishing and maintaining the status of fisheries. Fishery management fees are collected by the Government, and part of the fishing fees are redistributed to water area owners based on surveyed fishing days. Therefore, the price for a fishing day in the current situation ("cost cover" in Table 6. The outcomes of simulated exchange value (SEV) under different market conditions) is the same for all provinces.

Water area owners use the revenue from fees for fishery management in their water areas, and the rest is used for regional or national fishery management or to cover the transaction and administrative costs (see Figure 9). Whereas, additional fishing permits which are required to fish with specific gear or at special location can be sold for profit. In the context of this report, we use simulated exchange value method only on fishery management fees assuming that the price and quantity of fishing permits stays constant. We simulate four different market outcomes: i) current situation where management fees are sold to cover the costs, ii) competitive market, iii) monopoly and iv) revenue maximization for three areas of Finland that represent different types of fisheries and fishers. The difference between revenue maximization and monopoly is that for revenue maximization the marginal costs to supply the service are assumed non-existent. The areas included in the simulation exercise are the province of Southern-Savonia (Province 10 in Figure 3), Lapland and Finnish marine areas. Southern-Savonia is a popular region among second homeowners, and it includes parts of lake Saimaa, which is the largest lake in Finland as well as other smaller lakes that are mainly in good ecological status. Lapland is a popular fishing destination especially among fly- and other fishers targeting salmon. Marine regions differ from inland waters with respect to targeted species and fishers. Finally, we also simulate the market outcomes for the national exchange of fishery management fee fishing days.

In order to define the marginal cost and demand curves for recreational fishing days requiring the payment of management fees, we use the data on the management fee fishing days from survey ii) and the total collected fishery management fees allocated to provinces based on the amount of management fee fishing days. The demand functions are derived from a travel cost model by Pokki et al. (2021), where the coefficients for provincial travel costs α are used as the coefficients for the costs of management fees in an exponential demand function

$$\mathrm{Q} = Q_0 e^{\alpha P} \qquad (2)$$

Where Q_0 is the demanded amount of fishing days without management fee ($P = 0$) and P is the price of management fee. We solve the parameter Q_0 by setting values of Q and P in demand function to represent the actual situation in 2018, where collected management fees were collected to cover the costs of providing access to recreational fishing. This case is presented in the upper-left part of Table 6 (Cost cover).

Table 6. The outcomes of simulated exchange value (SEV) under different market conditions

	Cost cover				**Competitive**		
	fishing days	Price/day €	SEV €		fishing days	Price/day €	SEV €
Southern-Savonia	531102	1.23	653255.5	**Southern-Savonia**	512769	2.16	1107581
Lapland	443566	1.23	545586.2	**Lapland**	440450	1.56	687102
Marine areas	887369	1.23	1091464	**Marine areas**	887369	1.23	1091464
Finland	6326281	1.23	7781326	**Finland**	6266397	1.97	12344802
	Revenue maximization				**Monopoly**		
	fishing days	Price/day €	SEV €		fishing days	Price/day €	SEV €
Southern-Savonia	204697	26.4	5.41E+06	**Southern-Savonia**	197987	27.3	5.40E+06
Lapland	167430	47.8	8.01E+06	**Lapland**	163552	49	8.01E+06
Marine areas	329775	121	4.00E+07	**Marine areas**	326445	122	4.00E+07
Finland	2364510	77.6	1.83E+08	**Finland**	2334776	78.6	1.83E+08

The marginal cost curve to supply recreational fishing is defined using the collected management fees. We assume that the administrative and transaction costs, which represent 26% of total costs (see Figure 9) include fixed costs that are not dependent on the quantity of fishing days and costs associated to increasing returns to scale. Such expenses could result from for example maintaining the register of collected management fees and system to collect the fees, communication and fishing supervision. It is further assumed that the marginal costs for these inputs converge to zero as the number of fishing days increases. However, at the same time, we argue that the marginal costs to manage fisheries are zero (or negative) as long as the fish catch does not exceed sustainable yield. Sustainable yield is the yield/catch that can be extracted without causing degradation to the ecosystem (asset). The notion of negative management costs refers to capital gains stemming from improvements in the ecosystem, in this case from the growth of fish stocks.

If fish catch fell below sustainable yield, then the growth of fish stocks would exceed the yield resulting in capital gain. We assume that there are no fishery management costs (negative or positive) if the number of fishing days is lower than the number of fishing days equivalent to sustainable yield. For fishing days exceeding the equivalence to sustainable yield marginal costs of fishery management are defined by a convex function to represent the assumably decreasing returns to scale associated with the fishery management measures to compensate for the ecosystem degradations. Due to the assumptions related to marginal costs, we fit a convex quadratic marginal cost functions ($MC(Q) = a + bQ + cQ^2$, where $c > 0$) to the provincial data on the actual use of revenue from management fees to capture the nature of fixed costs as well as increasing and decreasing returns to scale.

The results of Table 6 show that the current (“Cost cover”) prices and supplied and used quantities of fishing days for all provinces are quite close to the outcomes of competitive market, where marginal costs equal the demand defined by marginal value of fishing days. This is true especially for Marine areas. However, in the monopoly outcome where marginal revenue equals marginal costs, and in the outcome, where revenue is maximized neglecting the costs and $P = -\frac{1}{\propto}$ the supplied and used quantities are significantly lower and the price of fishing days significantly higher than in the competitive and “cost cover” case. Intuitively the simulated exchange value (SEV) is higher for monopoly and revenue maximization outcome, because simulated exchange value equals the revenue, and in monopsony and revenue maximization the optimization is based on the revenue either with or without costs. All the outcomes for different provinces are illustrated in Figure 10. The results indicate that if the legislation related to the pricing of fishery management fees was changed so that the fee could be set freely by the supplier, this would have significant impacts on the supply, use and price of fishing days only if the supplier was a monopoly.

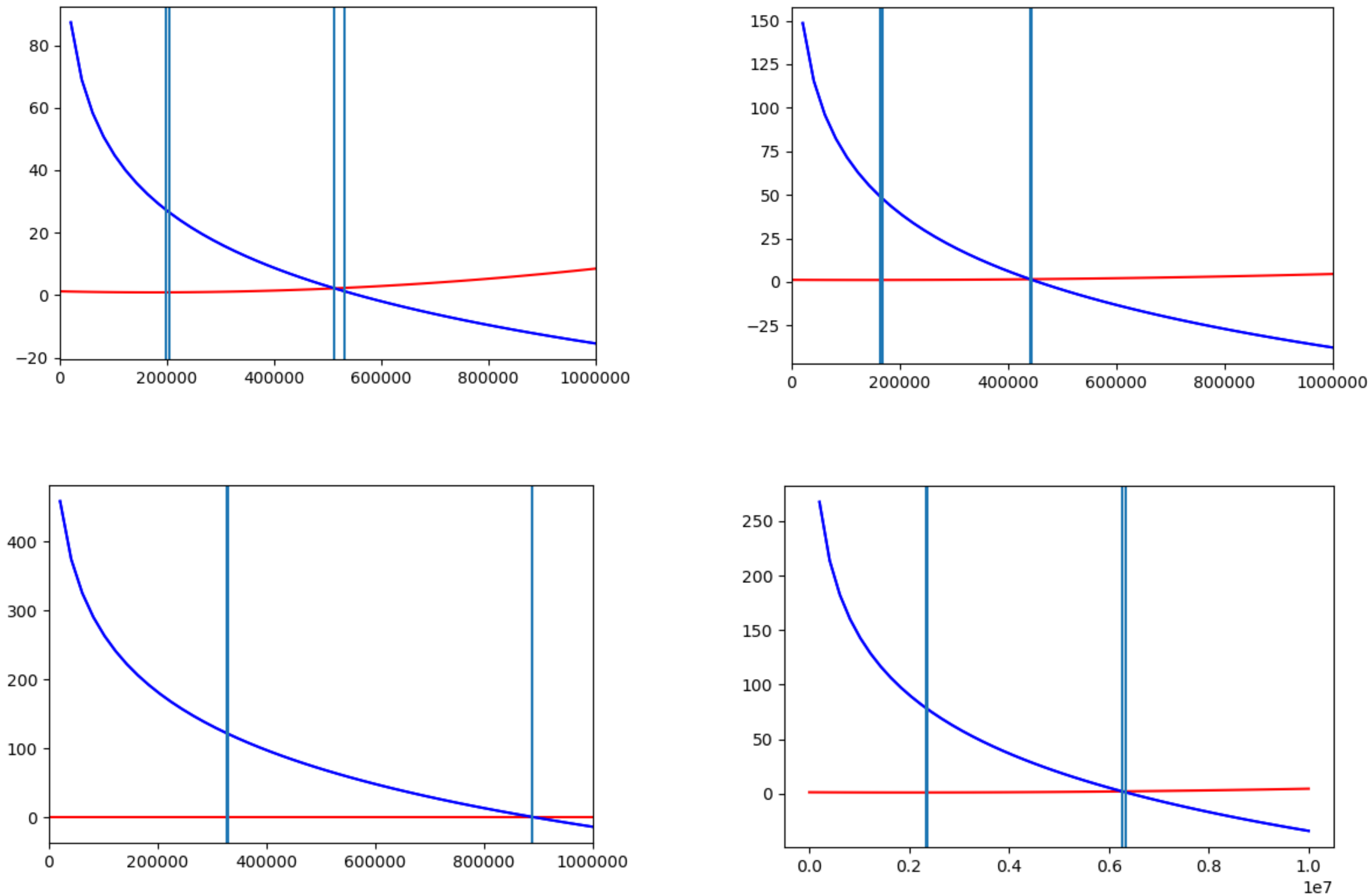


Figure 10. Illustration of SEV outcomes (top-left: Southern-Savonia, top right: Lapland, bottom-left: Marine areas, bottom-right: Finland): Demand curve is blue and marginal cost curve red. The lighter blue lines from left to right in each figure indicate monopoly, revenue maximization, competitive market and cost-cover outcomes

2.5 **Piloting national ecosystem service supply and use accounts for aquatic ecosystems**

2.5.1 Methods for compiling supply and use accounts for provisioning ecosystem services

The value of fish provision services from marine and freshwater commercial fisheries is valued as resource rent. The calculation of resource rent was revised from the approaches explored in the previous Eurostat Grants project (Vihervaara et al. 2018). Compared to the old approaches, an additional component, opportunity cost of capital, was included in the calculation of resource rent (see Table 7) based on the resource rent formulation in the SEEA EA (UN 2021).

For both marine and freshwater, the value of total income without subsidies (A in Table 7), intermediate input costs (B in Table 7), consumption of fixed capital (D1 in Table 7), and wages and unpaid labour (F in Table 7) were obtained directly from the national statistics or STECF (see the data sources of economic performance data of commercial marine fishing and commercial freshwater fishing in Table 1). For the marine case, opportunity cost of capital (D.2 in Table 7) was also obtained from the national statistics, while the national statistics for freshwater commercial fisheries did not include this information. To align with the marine case, the opportunity cost of capital was calculated by multiplying the value of fixed assets by the real interest rate. The real interest rate from STECF (2020) and the value of fixed asset from Luke (2021) were used to estimate opportunity cost of capital for freshwater (D.2 in Table 7). The real interest rate in 2018 was negative (STECF 2020), resulting in a negative opportunity cost of capital for both marine and freshwater cases.

However, the results between freshwater and marine are still not comparable, due to differences in the approaches for estimating the consumption of fixed capital (D1 in Table 7) between freshwater and marine fishery statistic. For the marine fleet, the consumption of fixed capital was calculated using the Perpetual Inventory Method (Pokki et al. 2018), while the consumption of fixed capital for freshwater fisheries was based on the financial statement data from the Structural business and financial statements statistics from Statistics Finland (Luke, 2021).

Table 7 displays the resource rent of fish provisioning services from marine and freshwater commercial fisheries by gear types (and vessel length for marine cases). The resource rent by gear types can be further disaggregated by species, based on the percentage of catch weight of specific species over the total catch, by gear types. Tables in Supplementary material 1 show the calculation of resource rent by species for 2018. For freshwater species, vendace had the highest total resource rent due to the highest harvest weight, and salmon had the highest unit resource rent. The unit resource rent ranged between 0.1-0.75 EUR/kg for different species. For marine species, herring has the highest total resource rent due to the highest harvest weight, and vendace has the highest unit resource rent. Except for herring, sprat, and vendace, the resource rent for the rest of the species was negative, as these are mainly harvested by passive-smaller scale fleets with negative net resource rent (see Table 7). Total resource rent is the input value that should be used to fill the national monetary supply and use account.

Table 7. Resource rent calculation of fish provision services from freshwaters and marine commercial fisheries in 2018.

	Freshwater						Marine					
Gear types	**Trap**	**Gillnet**	**Drag-net/seine**	**Trap net**	**Trawl**	**Total**	**PGVL0010**	**PGVL1012**	**TMVL1218**	**TMVL1824**	**TMVL2440**	**Total**
A: Total income without subsidies	473 891	3 741 897	1 520 078	1 717 107	3 139 147	10 592 120	7 490 794	1 152 906	4 588 784	3 567 363	20 759 654	37 559 501
B: Intermediate input costs	209 073	1 738 014	913 145	863 724	1 197 675	4 921 631	2 730 028	569 604	1 028 639	1 148 254	9 533 094	15 009 619
C: Gross value added (C=A-B)	264 818	2 003 883	606 933	853 383	1 941 472	5 670 489	4 760 766	583 302	3 560 145	2 419 109	11 226 560	22 549 882
D.1: Consumption of fixed capital = depreciation of capital	80 802	422 029	141 636	168 602	270 018	1 083 087	3 723 726	583 434	659 503	907 170	5 197 717	11 071 550
D.2: Return on produced assets (opportunity cost of capital)	(23)	(3 487)	(921)	(891)	(2 314)	(7 637)	(110 651)	(16 730)	(16 794)	(23 013)	(131 067)	(298 255)
E: Net value added (E=C-D.1-D.2)	184 039	1 585 341	466 218	685 672	1 673 768	4 595 039	1 147 691	16 598	2 917 436	1 534 952	6 159 910	11 776 587
F: Wages and unpaid labour	133 711	857 990	408 520	630 479	983 677	3 014 377	1 396 305	288 541	642 058	1 467 929	4 441 652	8 236 485
G: Gross resource rent (G=C-F)	131 107	1 145 893	198 413	222 904	957 795	2 656 112	3 364 461	294 761	2 918 087	951 180	6 784 908	14 313 397
H: Net resource rent (H=E-F)	50 328	727 351	57 698	55 193	690 091	1 580 662	(248 614)	(271 943)	2 275 378	67 023	1 718 258	3 540 102

Unit: €

2.5.2 Results of supply and use accounts

The supply and use accounting tables can be seen in Supplementary material 2. All the commercial catch and resource rent of both marine and freshwater ecosystem services are included (ES 1-1 in the supply and use table). The recreational catch is also included as provision services (ES 1-2 in the supply and use table) according to the SEEA EA (UN 2021), while recreational fishing days can be used to measure the use of recreation related services (ES 2-1 and 2-2 in the supply and use table). For the recreational services in the monetary supply and use account, not all the valuation results from chapter 2.4.2 are included. Only the value of recreational fishing days requiring management fee are included to demonstrate the accounting results. In the physical terms of the supply and use account, an intermediate service is demonstrated with salmon (smolt and spawners) which migrate between river and sea. The data of salmon smolt and spawners arriving at the river mouth are from ICES (2019a) and Palm et al. (2022), respectively. The later one was based on the underwater salmon count device and thus lower than the stock assessment from ICES (2019a) which were used as parameter input for modelling for the asset account in the next chapter.

2.6 **Piloting national asset accounts for aquatic ecosystems**

2.6.1 Application of bio-economic modelling for asset accounting

Bio-economic modelling has been tested in the previous Eurostat Grants project (Vihervaara et al. 2018) and Lai et al. (2018) to estimate the asset value and compile the ecosystem asset account. This pilot (1) made a brief review of the available bio-economic models that are applicable to ecosystem accounting for aquatic ecosystems in Finland; (2) revised one of the models to test the case considering both (but partial) recreational and provisioning services in asset accounting; (3) explored the linkage between asset accounting results, supply and use accounts as well as the asset accounting results from the species that do not have bio-economic models available (also see next section), by exploring suitable parameter setting and input data used in the bio-economic model; (4) demonstrated the asset account with an exercise of decomposed NPV change based on the SEEA EA suggestion (UN 2021).

The reviewed models are shown in Table 8. The included models can consider multiple fish-related ecosystem services, multispecies (food web interaction), or ecosystem conditions. These models can simulate the future flows of ecosystem service either for the most important commercial species or the most valuable recreational species in Finland. The table also lists the ways recreational fishing is integrated in current bioeconomic models and proposes ideas for developing the models to meet the requirements of asset accounting for different types of services.

Models No. 1-4 integrated the recreational service and the provisioning services in different ways, but they all need to be revised to better establish the linkage with the valuation of recreational service (chapter 2.4.2) in the service account.

There is a benefit when applying bio-economic models in estimating the net present value (NPV) of the asset. With proper parameter setting, these models are possible to include the price effects and volume effects from condition and demand change in simulating future service flows and values. Price effects include the expected change of unit resource rent, inflation rate, and discount rate (UN 2021), which can be included in the reviewed model by changing the parameter setting or functions of unit resource rent change. Volume effects caused by condition change (UN 2021) are reflected in fish population growth or decline with the setting of biological parameters in all these models. In addition, model no. 5 is an example of the bio-physical type of ecosystem condition (salinity) that can be included in the bio-economic model. The volume effects caused by demand change can be from the changes in harvest rate (fishing mortality), catchability, or fishing days with higher level assumptions such as population increase or more tightened quota from the policy request (UN 2021). Table 9 summarises how the reviewed models consider these effects and how these effects correspond to different entries in the asset account. Table 9 also compares the description of the entries for asset accounts in the SEEA EA (UN 2021) and the SEEA CF (UN et al. 2014), as the provisioning services of fish are also regarded as a single natural resource type that has a detailed description in the SEEA CF. It can be noticed that the entries of the asset account have more sub-items for natural resources, but the entries of the asset account in the ecosystem account are more aggregated.

*Table 8. Summary of the reviewed bio-economic models that are applicable to ecosystem accounting for Finland. *Studies that developed models belonging to the same series of models are classified in the same row.*

<table>
<tr><th>No.</th><th>Study that developed the models*</th><th>Commercial species (provisioning service)</th><th>Commercial fishing area</th><th>Recreational species (recreational service)</th><th>Recreational fishing area</th><th>Existing integration of recreational service in the model</th><th>Possible model extension for accounting</th><th>Other ES or ecosystem condition</th></tr>
<tr><td>1</td><td>Kulmala et al. (2008)</td><td>Salmon</td><td>Baltic Sea</td><td>salmon</td><td>Simojoki</td><td>Linear marginal willingness to pay for recreational catch</td><td>-</td><td>Fish stock</td></tr>
<tr><td>2</td><td>Oinonen et al. (2016)</td><td>Salmon</td><td>Baltic Sea</td><td>salmon</td><td>multiple rivers</td><td>Biological and economic effects, demand for recreational catch, dependent on coefficient and elasticity</td><td>Integrate with No.3 or 4 to have multiple rivers and food web interactions in the same model</td><td>Fish stock</td></tr>
<tr><td>3</td><td>Holma et al. (2014, 2019)</td><td>Salmon</td><td>Baltic Sea</td><td>salmon</td><td>Tornionjoki</td><td>Only biological effect of recreational fishing on the amount of eggs produced by spawners</td><td rowspan="2">Link the recreational parameters to the recreational harvest and value in the service account</td><td>Fish stock, grey seal</td></tr>
<tr><td>4</td><td>Lai et al. (2020, 2021, manuscript)</td><td>Salmon, herring</td><td>Baltic Sea</td><td>salmon</td><td>Tornionjoki</td><td>Biological and economic effects, demand for recreational catch, dependent on coefficient and elasticity</td><td>Fish stock, grey seal, non-use and bequest value</td></tr>
<tr><td>5</td><td>Nieminen et al. (2012, 2016)</td><td>Cod, herring, sprat</td><td>Baltic Sea</td><td>-</td><td>-</td><td>-</td><td>Integrate with No. 4 to have both most important commercial and recreation species in the same model</td><td>Fish stock, salinity level from climate effects</td></tr>
</table>

Table 9. A comparison of the asset accounts entries in the SEEA CF and the SEEA EA, and how these entries can be covered in the bio-economic model. References: SEEA EA (UN 2021) and SEEA CF (UN et al. 2014)

SEEA CF entry		SEEA EA entry	Included Items	Which model in Table 8 can cover
Growth in stock (+)		Ecosystem enhancement (+)	-Natural growth (SEEA CF) -Value increases from volume effects: volume increases (future flows of ES increase) due to improved condition (SEEA EA)	Model No.1-5, with biological parameters and population dynamics
Upward reappraisals (+)		Upward reappraisals (+)	-Parameter changes of the stock assessment model (SEEA CF) -Value increases from volume effects: volume increases (future flows of ES increase) due to increased demand (SEEA EA)	Model No.1-5, with the changes in harvest rate (fishing mortality), catchability, or fishing days in the future years
Reclassifications (±)		ecosystem conversion (±)	-capture for seeding and cultivation (-) or release for stocking (+) (SEEA CF) -Change of ecosystem type (extent change) (SEEA EA)	None of the models include this, but potential to consider
Gross harvest (-)	Depletion (-): if gross harvest> sustainable level or gross harvest + normal losses> growth	Ecosystem degradation (-): only extraction at rates above the rates of regeneration should contribute to degradation	-Landing + discard + other types of losses before landing (SEEA CF)	Model No.1-5, from services accounts or with parameter setting on harvest rate (fishing mortality), catchability, or fishing days, to make sure the levels align with service account
Normal losses (-)			-Natural loss (SEEA CF) -Value decreases from volume effects: volume decreases (future flows of ES decrease) due to decreased condition (SEEA EA)	Model No.1-5, with biological parameters and population dynamics
Catastrophic losses (-)		Catastrophic losses (-)	-Unexpectedly large losses due to disease or natural catastrophic events (SEEA CF, SEEA EA)	None of the model include this, but the concept of include climate effect from No.5 can be a reference if such cases would like to be included in the model
Uncompensated seizure (-)		-	-Harvest from Illegal fishing (SEEA CF)	None of the models include this, but potential to consider
Downward reappraisals (-)		Downward reappraisals (-)	-Parameter changes of the stock assessment model (SEEA CF) -Value decreases from volume effects: volume decrease due to decreased demand (SEEA EA)	Model No.1-5, with the changes in harvest rate (fishing mortality), catchability, or fishing days in the future years
Revaluations (±), only in monetary account		Revaluations (±), only in monetary account	-changes in unit prices of ecosystem services, including change in inflation rate and discount rate (SEEA EA)	Model No.1-5, with function to predict unit resource rent, and parameter setting of inflation rate and discount rate

In this pilot, the model developed by Lai et al. (2021) (No.4 in Table 8) was revised and applied to estimate the asset value of salmon, herring and sprat, to explore the possibility, difficulty and possible practical ways of applying bio-economic modelling to consider both provisioning and cultural services, form both marine and freshwater ecosystems. Lai et al. (2021) developed the model to cover the commercial harvest of salmon (Tornionjoki) and herring (population in Baltic Sea SD 30 and SD 31), and their foodweb interactions with grey seals. In Lai & Saikkonen (2020), the model included the influences of recreational harvest on the stock by adopting the recreational harvest rate that catches a proportion of homing migration salmon in the river from Holma et al. (2019) (Model No. 3 in Table 8). In this pilot, the recreational harvest rate was adjusted to make the modelled recreational harvest in the first year close to the harvest amount from the statistic (Table 10). We also extended the model to include the sprat model based on Nieminen et al. (2012) (No. 5 model in Table 8). The species and modelling scope that were covered in this revised model can be seen in Table 10.

In the model, the biological parameters (stock-recruitment parameter, natural mortality, initial population by age and weight, etc.) and the fishery-related parameters (fishing mortality, fishing days, and catchability) were all updated to the 2018 level based on ICES (2019a, 2019b, 2021) and STECF (2020). With these input data, the modelled harvest in the first year from the model is close to the statistical results that align with the ecosystem service supply and use table (Table 10). The slight differences between modelled results and statistics will be discussed in the asset account results.

Table 10 also summarizes the Finnish catch from the statistics within the modelling scope (e.g., Finnish herring catch in from Baltic Sea SD30 and 31). Their percentage of Finnish total catch and the correspondent resource rent will be excluded from the NPV of future resource rents to calculate the asset value in the next subsection 2.6.2. Their percentage of the total catch of the model scope (including catch from other countries) was used to allocate the asset value from the stock assessment scope to Finland. To align with the ecosystem service supply and use account, the unit resource rent of each species in 2018 (estimated in chapter 2.5.1) was used as the first-year value of the services. The unit resource rent was then assumed to increase with the inflation rate for future years. We used the inflation rate and the discount rate in the 2018 level from STECF (2020) to calculate NPV, following the same value used to calculate the opportunity cost of capital when estimating the resource rent for the supply and use account.

*Table 10. Summary of model scope and its relation to the statistic that use for supply and use account. *OSF (2021) and STECF (2020). STECF (2020) uses the data from OSF (2021), so the data in the same scope are aligned, but STECF (2020) has data that match for modelling scope publicly available. OSF (2021) was also used to compile supply and use account and species resource rent. **OSF (2021), same source to compile supply and use account and species resource rent. ***Based on species resource rent estimated in chapter 2.5.2 and the percentage in above role. **** Palm et al. (2022).*

Species		Salmon	Herring	Sprat
Stock basis for modelling (scope)		Tornionjoki	Baltic Sea SD 30 +SD31	Entire Baltic Sea
Harvest scope		Commercial harvest at sea, recreational harvest at river	Commercial harvest at sea	Commercial harvest at sea
The first year of Finnish part of the harvest from modelling (ton)	Commercial harvest at sea	120	86 185	16 365
	Recreational harvest at river	80	-	-
From statistic (algin with supply and use account)				
Commercial harvest at sea	Finnish harvest within the scope (ton)*	113	81 140	16 455
	Percentage of total Finnish catch**	55%	64%	100%
	Correspondent resource rent (EUR)***	(-4,539)	2 159 404	343 945
	Percentage of total stock assessment scope*	Uncertain due to the Swedish catch data	83%	6%
Recreational harvest at river	Finnish harvest within the scope (ton)****	75	-	-
	Percentage of total Finnish catch**	37%		
	Correspondent resource rent***	(3,014)	-	-
	Percentage of total stock assessment scope****	82%	-	-

The asset account with modelled asset value can be seen in Supplementary material 2, which reveals a couple of discussion points for compiling asset accounts in practice. First, the data for the entry in the physical terms of the asset account can also be directly obtained from ICES (2019a, 2019b) with the information on Finish catch share. The ICES reports updates the stock assessments of the important species every year. However, the future service flows and asset value can only be simulated and estimated with bio-economic models. Although the same ICES reports were used as data input for bio-economic modelling, slight differences between modelled results and the original assessment in terms of opening stock and harvest amount can be observed. To make the asset account match the supply and use account, such differences should also be revealed. In the demonstrated asset account in Supplementary material 2, such differences are recorded in an entry under reappraisals. The demonstrated asset account also reveals another issue regarding such differences—the closing stock from the model and from the stock assessment report can go in the opposite direction compared to the opening stock (see the sprat case in the table), even if the value is very close. It reveals a mismatch in ecosystem enhancement and degradation in the sprat case when the growth from the model was used in the case without the model, implying another way to connect the modelled asset account and services account, and the way to reveal such differences, needs to be further explored.

Another discussion point relates to the migration species in the physical asset account. Only the salmon spawner in the river, which should be classified as a freshwater ecosystem asset, is recorded following the suggestion from SEEA CF (UN et al. 2014). But when estimating the flows of the services that the asset can provide in the future, both services provided in both types of ecosystems should be included. Therefore, the calculated asset value represents the value for both freshwater and marine ecosystems. How physical terms and value of such migration species should be recorded in the asset account, and how it should link to the intermediate services demonstrated in the supply and use table, should be further explored.

The salmon asset shows a negative value in the monetary account, which results from the negative species resource rent from the marine supply and use account. But the value change between the opening and closing stock still reflects the ecosystem enhancement. The monetary results of herring seem to conflict with the physical asset at the first glance. However, by checking the population dynamics in the model, it can be seen that the decrease in the stock shown in the physical account is a short-term result. In the long-term, the modelled herring stock increases, which is reflected in the monetary results. Sprat shows an opposite case of herring that the short-term stock change in the model increases, but mid-term stock decrease, which leads to a decreased monetary value. The monetary asset account with modelled asset value also demonstrates the changes in the decomposed NPV, following the suggestion from the SEEA EA (UN 2021). The decomposed results match the net change and reveal the price effect correctly as expected. But the volume effects are not comparable to the physical accounting results due to the short-term and long-term differences in the population dynamics from the model.

2.6.2 Asset value for other species and recreational services

For the recreational service and the rest of the species that are not yet able to be included in the bio-economic model, a simple estimate of future resource rent was made. We assume that the physical supply and use of the services would be the same in the future as for the year 2018, but the nominal unit resource rent would increase with the inflation rate. Then, the future flows need to be discounted to calculate the NPV of the asset value (Supplementary material 2). We used the inflation rate and the discount rate in 2018 from STECF (2020) to calculate NPV level, which were also used to calculate opportunity cost of capital when estimating the resource rent for the supply and use account. The resulting real discount rate is negative for the year 2018 (-0.54%) which results into increasing net present annual values of resource rent for the future. For comparison, we further applied a discount rate of 5% for the NPV, without taking into account the effect of this changed interest rate on the opportunity cost of capital. The difference between the NPVs calculated using different interest rates can be seen in the supplementary material 2. With a positive discount rate, the annual net present values form a geometric series converging to zero, and thus also their sum converges to a certain value presented in the supplementary material 2.

2.7 Conclusions and lessons learnt

The main conclusions and lessons learnt are:

- Finland has extensive data collection on recreational fishing.
- However, this data is often collected using different spatial units, which makes it difficult to use data from different sources to compile accounts.
- SEEA EA recommendations on valuation methods provide diverse set of means to value recreational ES. But are the results comparable?
- More data and assessments are needed on the institutional context and on the demand (preferences and values) for recreational services.
- Simulated exchange value could be used to study the effects of changes in the institutional context and in the environment on the supply, use and value of recreation-related services.
- Linking demand and supply of recreational fishing to asset accounts is challenging.
- Applying bio-economic models has a benefit of reflecting the service flow changes based on the population dynamics simulated in the model and allows the inclusion of such changes in the value of ecosystem asset.
- A lot of consideration should be given to the selection of discount rate for valuing future ecosystem flows.
- However, a mismatch would happen in terms of the short-term stock change in the physical asset account and the value of monetary account that reflects the long-term stock change.
- Another mismatch would happen between modelled results for physical asset account and data from statistic or other stock assessment data that were used as modelling input data when attempting to establish the linkage and alignment between modelled asset valuation and the supply and use accounts.
- Such mismatches need to be addressed when applying bio-economics modelling for accounting in practice.

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3 Accounting for Urban Green (WP3)

Leena Kopperoinen[1], Laura Costadone[1], Tin-Yu Lai[1], Vuokko Heikinheimo[1], Pekka Hurskainen[1]
[1] Finnish Environment Institute (Syke)

3.1 Previous experiments in urban ecosystem accounting

The work conducted in Work Package 3 contributes to the development of ecosystem accounts, particularly thematic urban accounts co-developed together with Finnish municipalities. Urban ecosystem accounts are completely novel in Finland, and therefore the work is experimental with not much past experiences to build upon. Instead, accounting for urban green will result in practical experiences on what will work and what will not as well as data needs and sources, opening the door for further discussions and research on the applicability of ecosystem accounting in municipal decision making and urban planning.

Urban ecosystem accounting is experimental by nature as there are no standards for it yet. There have been developments in urban experimental ecosystem accounting in Britain, the Netherlands and most recently in Norway. The Urban EEA project (2017-2020) in Norway was funded by the Research Council of Norway[1]. During the project, urban ecosystem extent and condition mapping and accounting using remote sensing data were tested, and selected ecosystem services of high importance to the municipality of Oslo were mapped for the first time. Valuable experience was gained on the scale of effort required to compile a complete set of ecosystem accounts at municipal level, at the same level of ambition as envisaged by the SEEA EA for national accounts.

In addition, urban ecosystem assessments have been carried out at the EU level (EC/Joint Research Centre) as well as local pilots implemented in 18 city labs around Europe in the frame of EC's EnRoute project, and in pilot studies with Nordic municipalities (Kopperoinen et al, 2022). In this, indicators of biodiversity, ecosystem structure and extent, ecosystem condition, and ecosystem services supply and use were tested. Despite of all these pilots, urban ecosystem accounting is still in the beginning, especially in terms of municipal practice. Urban ecosystem accounting is a complex issue and covers versatile aspects of ecosystems in much higher spatial and thematic detail than national accounting does. In addition, it is highly intertwined with the municipal management and decision-making which adds challenges. To be able to bring ecosystem accounting as part of municipal overall accounting and get acceptability for it, it is of utmost importance to work in close cooperation with cities and municipalities themselves in the ecosystem accounting development and implementation.

[1] https://www.nina.no/english/Fields-of-research/Projects/Urban-EEA

3.2 Objectives

The overall objective of the urban green WP, as stated in the project proposal, says:

"Explore ways how to make urban green areas, and the benefits they give to people (as ecosystem services), inclusive, visible and accountable in urban planning and decision making".

Moreover, specific objectives were also set:

1. Test the feasibility of existing data (especially spatial) and methods for the purpose of urban EA.
2. Collaborate with municipalities of varying sizes and characteristics
    a. to learn about their needs in terms of urban EA
    b. to figure out availability of municipal data suitable for urban EA
    c. to test urban EA in three different real-world urban cases,
    d. to get feedback on the possibilities and challenges in implementing urban EA in different circumstances, and
    e. based on feedback, to report whether existing data and methods are applicable for urban EA purposes and how the municipalities can produce data that can be used directly at national level EA.
3. Produce pilot extent accounts for urban green areas suitable for cities and municipalities of different sizes
4. Use the above-mentioned urban green area assets to develop pilot supply and use accounts in physical and monetary terms for two selected ES with special importance for the well-being of urban inhabitants and/or municipal environmental targets.

As an **extra objective**, which relates to objective three above, we add

- Test the feasibility of cross-walking ecosystem types used in the pilots to the proposed EU ecosystem typology (Eurostat 2023)

3.3 Municipalities and their needs to be supported by ecosystem accounts

Activities in WP3 started with an internal kick-off meeting in March 2021. Stakeholder meetings with the three piloting municipalities Helsinki, Tampere and Pirkkala (see Figure 11) were held starting from April 2021, and five to eight meetings per municipality (20 meetings in total) were arranged in the reporting period. Out of these, four were face-to-face meetings and the rest online meetings. The first couple of meetings with each municipality served the function of defining the policy needs of the municipalities. Municipalities had also internal crosssectoral gatherings to agree on their most urgent policy questions needing support based on ecosystem accounts. In the later meetings, we discussed the middle-stages and final accounting results, as well as the validation and application of the accounting results. Between the meetings, stakeholder interaction, including discussions and sharing of data, was arranged virtually through a shared working space and through e-mail communication. In addition, three field visits to important urban green areas were arranged by Pirkkala and Tampere municipalities. The interaction with the city of Helsinki was not as close as with Pirkkala and Tampere due to, for example, loss of personnel in the city office serving as the main contact point for the urban ecosystem accounting piloting.

Figure 11. Location of piloting municipalities. Background map data from naturalearthdata.com.

Co-operation with the municipalities started by Syke researchers explaining what ecosystem accounting is, with specific emphasis on urban accounts. There was a significant variation in how much the staff of the different municipalities knew about ecosystem accounting, from detailed knowledge to complete beginners. Since only few practical examples existed of how urban ecosystem accounting has been implemented and how it is used in municipal decision making, it was often difficult for the municipalities to clearly state their needs and expectations for it. This was a learning process for both researchers and municipal officers.

As a first step towards the urban accounts, we made together a short list of a few ecosystem accounts that could be implemented in the pilots and compiled a list of data requirements for urban ecosystem accounting. After that we discussed the possibilities and options of ecosystem accounting, data availabilities, and methodological issues based on which the pilot municipalities decided which ecosystem accounts would be implemented. The precondition was that the municipality could identify a concrete political, planning-related or some other need for which the ecosystem accounts would provide important information.

The policy questions of each municipality were collected in the workshops through stakeholder interaction with the pilots. From these discussions, several cultural ecosystem services and regulating ecosystem services emerged as interesting topics to develop in our pilots. Health benefits from cultural ecosystem services were especially emphasized as important motivator for accounting. In the following subchapters, policy needs of our three pilot municipalities and our objectives for these case studies are discussed.

3.3.1 Pirkkala

Pirkkala municipality, located southwest from Helsinki, belongs to the Tampere metropolitan region (Figure 11). Compared to the other municipalities in this pilot, Pirkkala urban centre is relatively small and compact, and the eastern parts of the urban centre are conglomerated with the southern suburbs of Tampere, forming a rather dense continuum of settlement, industrial, and commercial areas.

In Pirkkala we focused on the different kinds of benefits and values provided by urban greenspace and forest ecosystems. Pirkkala's urban greenspace consists of different types of urban parks, sports and recreation sites. If the definition of urban greenspace is extended to include also nearby croplands, grasslands and forests in the rural Pirkkala, the significance of these ecosystem assets to Pirkkala residents can be studied in a more comprehensive way. Pirkkala's forests (Figure 12), some of which are owned and maintained for recreational use by the municipality, were of particular interest.

Figure 12. Lake Pulkajärvi (left), located in the Southern edge of Pirkkala, with good facilities and many trails traversing the forests surrounding it (right) are among the most popular ecosystems used by residents of Pirkkala and neighbouring Tampere for recreation. Photographs by Pekka Hurskainen.

In our first discussions with the municipality, ecological connectivity between these ecosystem assets and their biodiversity values were emphasized. In terms of ecosystem services and economic value, the recreational and educational services provided by the forest ecosystems and urban greenspace were of special concern. Especially the forest assets are under a threat of loss due to competing land use pressures, the increase of population and traffic volumes, as well as traffic noise pollution. In addition, when above certain threshold, recreational value potentially conflicts with the ecological value with increasing population and their demand for recreational use of the forest.

The municipality of Pirkkala has also an ambitious biodiversity programme for 2020-2030 (Pirkkalan kunta 2020). One activity in the programme is to experiment ecosystem accounting at municipal level, and the goal is to have at least one ecosystem account ready by 2025, and it will be maintained at least until 2030. Accounting for recreation ecosystem service supply and use is specifically mentioned in the programme.

3.3.2 Tampere

The City of Tampere was initially interested in variety of regulation and cultural services. Climate mitigation, cooling, pollination, and cultural ecosystem services, especially recreation, provided by the urban green and blue space (Figure 13**Error! Reference source not found.**) as well as relevant health issues popped up several times in the discussions.

Figure 13. Urban green and blue space in Tampere. Left: A restored stream (photo by Laura Costadone), right: Lake Iidesjärvi (photo by Tin-Yu Lai).

In the later meetings, the focus narrowed down to a critical issue for Tampere: mitigation of the effects of flooding caused by the extreme heavy rain events that have happened in recent years. Stormwater runoff has been found to be a major source of pollution in natural water systems due to the high concentration of nutrients and solids in water runoff. Flood management is a critical issue that is expected to gain even more importance in the near future due to rainfall intensification and landscape transformation linked to urbanization and deforestation. It is estimated that precipitation will increase in Finland by 25% in the next decades due to climate change. Heavy rain events are also assumed to become more intense. For stormwater management, Tampere was interested in the ability of flood mitigation ecosystem service provided by blue-green infrastructure within the municipal boundaries as well as its value. Urban stormwater flooding is a global challenge often caused by the reduced infiltration, retention and drainage capacity in cities. Stormwater load can be substantially reduced by urban blue-green infrastructure like patches of vegetation or forests that attenuate runoff during flash floods. Quantification of the benefits provided by natural infrastructures can allow the integration of this natural capital into decision making.

From the municipality's own wish, the Ecosystem Accounting Area (EAA) used for Tampere pilot accounts deviated from the official municipal boundary. Tampere central urban area, without the north-eastern part known as Teisko, was used instead.

3.3.3 Helsinki

The city of Helsinki, with a population of 658 000 inhabitants, is located in southern Finland in the Helsinki-Uusimaa Region (Figure 11). Helsinki is one of the greenest cities in Europe with green areas covering more than 40% of the city's land area. There are seven green wedges or "Green Fingers" extending from the outskirts to the city centre, and they form a continuum of green spaces that contribute to the healthy and sustainable urban life (Vierikko et al. 2014).

Figure 14. Töölönlahti urban park in Helsinki CBD. Photograph by Riku Lumiaro.

The rather extensive forested areas still left in Helsinki are managed to preserve biodiversity conservation and to provide important recreational and other cultural ecosystem services for its residents and visitors. Most of these green areas provide close-to-home recreational opportunities or are a day trip destination for a wide range of outdoor activities.

The city owns a considerable amount of green spaces within its boundaries and thus controls their development. Despite its importance, Helsinki's urban green is facing increasing pressure due to high land demand for urban development, similarly to many other rapidly developing urban areas (Simkin et a. 2020). In recent years, the intensification of existing suburbs and residential areas in Helsinki has meant that urban green, such as nearby forests which were enjoyed by residents, have been now converted for new housing and other impervious surfaces.

Therefore, Helsinki expressed their interest in piloting an extent account of its urban green assets, including urban greenspace, cropland and forests, and supply and use accounts of recreational ecosystem service and the health benefits provided by these assets for its residents and visitors (Figure 14). Integrating data on the recreational use and economic value of the urban green can help showing the importance of ecosystem services for people and mainstreaming this value into planning and economic decisions.

3.4 **Assessing the availability and feasibility of existing data**

In parallel to interacting with municipalities to identify their policy questions and needs and expectations towards this study, we concentrated our efforts in identification of available data sources and assessing their feasibility to populate the extent accounts and to be used for modelling and validating the ecosystem service supply and use. This was a foundational task, since it in effect dictated which types of ecosystem types and ecosystem services we would be able to use in our pilots and which had to be left out.

Lack of spatial data as such was not an issue. Spatial data are openly available in various portals and metadata directories, including data sharing platforms operated by the biggest municipalities such as Tampere and Helsinki. It was rather data completeness, applicability and suitability for urban ecosystem accounting, that disqualified the use of many datasets. This is not surprising considering that data at the municipalities and national authorities are collected for various purposes, and the intended use has strongly influenced the way the data was collected, modelled, and stored. We took this as a challenge and tried to see how far we can reach with existing data. In many cases, this required us to spend a lot of time pre-processing the different datasets to create as closely harmonized data as possible.

The first challenge was to identify the best data for populating the ecosystem extent accounts. We evaluated several options for each municipality, but in the following chapters we focus on the datasets actually used. Moreover, different priorities of the municipalities for ecosystem accounting also guided our decisions on which datasets the extent accounts would be based on. As a result, the extent accounts of the three pilot municipalities each had different typologies and input datasets. Only one of the extent accounts can be considered “complete” as it accounts for opening and closing extents of all ecosystem types, the other two can be considered “partial” extent accounts.

The second challenge was to identify appropriate data for modelling the ecosystem service supply and use accounts in physical and monetary terms. Particularly challenging was to find suitable data to validate modelling results and to estimate the ecosystem service flows to their users or for valuation. It is often that the ecosystem services are measured at the potential supply level, but not the actual supply and use level that is required for accounting context. Further, sometimes ecosystem service flow data is estimated in units that match with the suitable valuation method. Social media and movement data, which are considered to approximate some of the service flows, are inherently biased as they represent only a small proportion of the population, which may affect the representativeness of the data sample.

In the following sub-chapters, we discuss more the characteristics of the data we used for the extent and ecosystem service supply and use accounts in the piloting municipalities. Full list of the used datasets together with their technical details are given in Table 11.

Table 11. Datasets used for urban ecosystem accounting pilots (next page).

Dataset	Use	Datatype	Spatial resolution / scale	Spatial extent	Temporal extent	Update frequency	Source	Metadata
Administrative boundaries	ecosystem accounting area	Polygon	1:10 000	Finland	2020	on demand	NLS, TK	Link
Pirkkala urban greenspace maintenance classes	extent	Polygon	unknown	Pirkkala (town plan area)	2021	on demand	Pirkkala	n/a
Gridded forest resource data (*Hila*)	extent	Polygon	16 x 16 m	Finland	2013 - 2022	continuous / on demand	SMK	Link
Forest stands (*Metsävarakuviot*)	extent	Polygon	unknown	Finland	2022	continuous / on demand	SMK	Link
Forest mask (commercial forestry and protected areas) (*Metsämaski*)	extent	Polygon	unknown	Finland	2022	continuous / on demand	SMK	Link
Canopy height model	extent	Raster	1 x 1 m	Finland	2008-2022	continuous, 1-2 /year	SMK	Link
CORINE Land Cover (High-res accounting layers)	extent	Raster	20 x 20 m	Finland	2012, 2018	6 years	Syke	Link
Urban Atlas	extent	Polygon	1: 10 000	Helsinki	2018	6 years	Syke, EEA	Link
Register of public areas (*YLRE*) - urban greenspace maintenance classes	extent	Polygon	unknown	Helsinki	2022	on demand	Helsinki	Link
Locations of schools and daycare centres in Pirkkala	ES use, physical	Point data	unknown	Pirkkala	2022	unknown	Pirkkala	n/a
Number of enrolled students in schools in Pirkkala	ES use, physical	numerical		Pirkkala	2022	unknown	Pirkkala	n/a
Catchment areas	ES use, physical	Polygon	1:50 000	Tampere	2021		Syke	Link
Depth of rainfall	ES use, physical	numerical (mm)	constant	Tampere	2022		Finnish Meteorological Institute	
Superficial deposits of Finland	ES use, physical	Polygon	1:20 000	Tampere	2015		Geological survey of Finland	Link
Strava sports application data	ES use, physical	Point	unknown	Helsinki	2019		Strava Metro	
Eco-counter data	ES use, physical	numerical	unknown	Helsinki	2019		Helsinki	
National inventory of outdoor recreation (LVVI)	ES use, physical	numerical	National	Finland	2019-2020	10 years	Luke	Link
Population according to age and gender by area	ES use, physical	numerical	Municipality	Helsinki	2019	1 year	Statistics Finland'	Link

Dataset	Use	Datatype	Spatial resolution / scale	Spatial extent	Temporal extent	Update frequency	Source	Metadata
Building footprint	ES supply and use, monetary	vector	Municipality/1:5000 - 1:10 000	Tampere	2012, 2018	continuous	Tampere	Link
Wooden constructions	ES supply and use, monetary	vector	Municipality/1:5000 - 1:10 000	Tampere	2012, 2018	Continuous/on demand	Tampere	Link
Building cost index	ES supply and use, monetary	Numerical	National	Finland	2010, 2012, 2018	1 year	Statistics Finland	Link
Unit reactional value of Finland	ES supply and use, monetary	Numerical	National	Finland	2020		Lankia et al. (2020)	

3.4.1 Municipal data for urban green extent

In our project proposal we assumed that urban greenspace that are under the maintenance classification could be used as assets for urban ecosystem accounting. At least in the largest municipalities, such as Helsinki, these are part of the Register of Public Areas (*Yleisten alueiden rekisteri*, YLRE). They are maintained by municipalities and offer the highest spatial detail of urban green assets in Finland. The classification is based on recommendations given by The Finnish Association of Landscape Industries in 2007 for a common typology of urban green spaces in Finnish municipalities, also known as the "ABC-typology". In the typology, green spaces are classified based on their use and level of maintenance efforts required by the municipality. The typology was recently revised in 2020 (now known as "RAMS-typology") to include a wider set of maintenance aspects, and for the first time, ecological and biodiversity values were also incorporated in the design (VYL 2022).

The maintenance classification is in fact a tool which helps municipalities to make their green spaces commensurable in their overall appearance, use, quality, and cost factors (VYL 2022). It can include (1) built-up green spaces such as urban parks, cemeteries as well as sport and leisure areas, (2) open green spaces such as croplands and meadows, (3) forests and (4) protected areas. The different types of maintenance classes have also different sets of objectives. For example, the objective of maintaining open green spaces is to safeguard their species diversity, keep the landscape open by frequent weeding and mowing and to make sure the open spaces can sustain the use pressure. Forests, on the other hand, are maintained to ensure and sustain forest vegetation and soil vitality, health, growth, power to regenerate, and biodiversity. The municipality can also decide to change the maintenance class of an urban green space as it is being developed, for example when the intensity of the maintenance efforts is reduced or increased, or if the intended use of the green space changes (VYL 2022).

The typology allows municipalities to include both public and privately owned green spaces. However, in practice all three piloting municipalities had only municipality-owned green spaces in their registers. This should be acknowledged as a considerable limitation when considering the feasibility of maintenance classification towards urban EA. However, if the interest is in how the extent, condition or both physical and monetary value of ecosystem services supply and use change over time in areas maintained differently, maintenance classes can be used as applied ecosystem types.

At the time of project implementation, only Tampere had shifted using the new RAMS typology, while Pirkkala and Helsinki were still using the older ABC typology. Feasibility of maintenance classes for accounting for urban green was tested for Pirkkala and Helsinki.

3.4.2 National data for extent

In addition to municipal data, we investigated nation-wide datasets produced by Syke, Luke, Statistics Finland (TK), Finnish Forest Centre (SMK), and National Land Survey of Finland (NLS). The following nation-wide datasets were found to be most useful for modelling ecosystem extent at municipal level (see Table 11 for details):

- Administrative municipality boundaries co-produced by NLS and TK were used for delineating the EAA.
- CORINE Land Cover (CLC) high-resolution accounting layers modelled in raster format. This is a harmonized time-series of land cover produced by Syke, covering years 2000-2018 in six-year intervals. CLC is the only nation-wide land cover dataset that covers all ecosystem types (except for marine ecosystems). Due to these two very important characteristics, it can be considered accounting-ready-data as complete ecosystem extent accounts can be compiled and changes in the extent can be followed. While it can be considered high-resolution for national purposes, the pixel size of 400 m^2 is not the most optimal for highly heterogeneous urban ecosystems, however.
- SMK forest resource data for modelling the extent of forest ecosystem types. SMK is mandated to collect and share information on Finnish forests under the direction and financing from Ministry of Agriculture and Forestry. SMK forest stand data (Figure 15, left) are the most up-to-date and reliable data source at stand level, while the gridded forest resource data (Figure 15, middle) and canopy height model (Figure 15, right) add more details collected through remote sensing methods. The Forest mask (of forests under commercial forestry and protected areas), on the other hand, doesn’t have delineations of individual forest stands, nor any attribute data. Instead, it contains very large polygons containing nearly all forest extent in Finland, including protected areas. Combination and harmonization of these multiple datasets is necessary as there is no single accounting-ready dataset that would capture all forest ecosystems in Finland. By combining data from different SMK datasets, it is possible to create forest extent account following the EU ecosystem typology at level 2 (Eurostat 2023). The biggest limitation of using SMK data is that no historical versions of forest resources are saved at the moment (any updates are overwriting the previous information), so only forest ecosystem extent at present is possible to compile.

- Urban Atlas land cover / land use time-series covering years 2006, 2012 and 2018. Covers the seven largest cities and metropolitan areas in Finland (including our pilots). Data in vector polygon format is produced by EEA and validated by Syke.

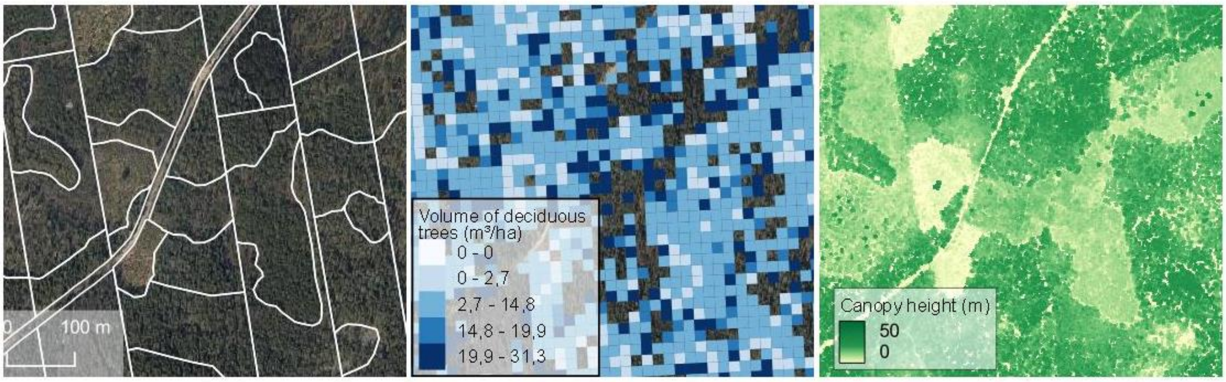

Figure 15. Examples of SMK forest data: Forest stands (left), Gridded forest resource data (middle), Canopy height model (right). Background aerial photographs by National Land Survey of Finland.

3.4.3 Data for ecosystem services supply and use

For **Pirkkala**, educational and recreational ecosystem services supplied by urban green and forests were selected to be compiled in the ecosystem service supply and use account. To compile the account and value the services, quantified visiting numbers (and/or visiting time) are the minimum required data (NCAVES and MAIA 2022, UN 2021). Quantified visiting data usable for modelling or estimating these two services at the municipality scale didn't exist. Based on local knowledge and previous research done at Pirkkala municipality, only the most popular and widely used urban green hotspots could be identified, which is not enough for valuing the services and for compiling the accounts. Therefore, two surveys were planned and conducted in this project to collect the necessary data to quantify the physical term of the services. In the recreational survey, monetary data were collected simultaneously. Also, for educational ecosystem service, the needed data for monetary valuation was collected in this study. The detail of survey design, survey conduction, and data collection are described in chapter 3.6.1. Based on the piloting experiences in this project, a small municipality such as Pirkkala should be capable to repeat the surveys in every few years to follow up how the use of these ecosystem services is developing. To upscale the educational services from survey results to Pirkkala level, the number of enrolled students/children, name and location of all school and day-care centres in Pirkkala were provided by the municipality.

For **Tampere**, we used the InVEST Urban Flood Mitigation Model (Integrated Valuation of Ecosystem Services and Tradeoffs, version 3.8.6, 2019) to calculate the physical supply of flood mitigation ecosystem service provided by green areas. This model utilizes the US soil conservation service-curve number (SCS-CN) method to quantify the potential impact of different ET in the runoff process and consequent potential flooding. The run-off CN are dimensionless values that vary between 0 and 100 and are empirical estimations of the run-off generation (lower numbers indicate low runoff potential while large numbers indicate high runoff potential). The model quantifies the runoff based on a precipitation event (P in mm) received over the study are and the ET characteristics. A precipitation depth (P) of 24 mm was estimated by averaging the four highest historic precipitation events. To simulate the impact of potential future climate change scenario, the model was also run considering a single rain event of 50 mm, which has been established as a threshold of cloudburst, according to Rosenzweig et al. (2019). The InVEST model requires a vector delineating the watershed of the study area, the raster layer of hydrologic soil group, land use land cover, and curve number (CN) over the study area.

The flood depth-damage model was used to value the flood mitigation service (see chapter 3.6.2). To adjust the model parameters to Finnish context, we used information on building use, age, and construction material from the building footprint and wooden construction maps of Tampere, as well as building cost index of Finland. These three data sets for valuation are continuously updated either by the city of Tampere or by Statistics Finland. To align with extent account, data in 2012 and 2018 was used.

Helsinki, similar to Pirkkala, lacked data on visiting numbers to quantify the use of recreational ecosystem service. To approximate the use in physical terms without conducting a survey, the National inventory of outdoor recreation (LVVI), population statistic of Helsinki, recreational activity data from the sport application Strava and eco-counter data were used. Data for LVVI and population can be collected from the national data, while the former one is updated every 10 years and the latter one updated every year.

Strava data were acquired via a partnership with Strava Metro that delivers de-identified information on pedestrian and cycling trips aggregated to road and path segments from OpenStreetMap. Daily Strava activity counts for both cycling and pedestrian activities for the year 2019 were retrieved from the Strava Metro service and aggregated by month. The accuracy of Strava activity count data was assessed by comparing data collected by six fixed-point counter stations (EcoCounter with two-way pyroelectric sensor) located across our study area. For monetary term, value per visit at national level was used, which was estimated by Lankia et al. (2020) with LVVI data (see chapter 3.6.3.4).

3.5 Testing and piloting ecosystem extent accounts

3.5.1 Pirkkala Forest and Urban Green Extent Account

Pirkkala prioritized cultural ecosystem services provided by forest and urban green ecosystems using the municipal boundary as the ecosystem accounting area, so we developed a workflow for geoprocessing a harmonized spatial dataset for these assets (instead of aiming for an exhaustive mapping of all ecosystem types). Moreover, we aimed to align the typology to

Eurostat's proposed EU typology for ecosystem accounting (Eurostat 2023) at level 3 as much as possible (see Table 12). Both municipal and national data were used for the extent, which had the following characteristics:

- From the first ET at level 1 - *Settlements and other artificial areas* – we included the urban greenspace under maintenance classification and owned by the municipality. Four ETs at level 3 could be distinguished based on available data.
- From the second ET at level 1 – *Cropland* – we included cropland which is under maintenance classification and owned by the municipality. These croplands provide primarily aesthetic and recreational ecosystem services, instead of food provision. Privately owned cropland was omitted.
- From the third ET at level 1 – *Grassland* – we included assets under maintenance classification and owned by the municipality. These include modified grassland providing aesthetic and recreational ecosystem services, and high-nature value meadows important for biodiversity. Privately owned grassland was omitted. Based on available data, three modified grassland ETs and one semi-natural grassland ET could be separated at level 3.
- From the fourth ET at level 1 – *Forests and Woodlands* – we aimed to get full coverage of all forest and woodland types in the municipality. Forests under maintenance classification and owned by the municipality were grouped together at level 2 as "Other forests", and further subdivided to three ETs at level 3. The remaining forests, with different ownership, were classified separately based on their ecological / structural characteristics (tree species composition, mean tree height and canopy cover) into four ETs at levels 2 and 3. While all forests in Finland can be used for recreation purposes following the everyman's right, municipality-owned forests are usually not used for timber provision, which is an important distinction.

The reason for omitting privately owned areas was due to our will to test the feasibility of maintenance classes as ecosystem types in urban ecosystem accounting. In urban areas most of the publicly accessible green space is owned by municipalities which have the power of deciding on how the areas are maintained. This affects furthermore the condition and recreational or educational use possibilities of these areas. Ecosystem accounts could thus provide important information on the status of differently maintained green areas for deciding on further maintenance work and classification of them.

We used the Pirkkala Urban Green Maintenance classification as it was, only assigning the maintenance class into its appropriate ET in our typology. Forests not in the maintenance classification were processed separately using SMK data, which is elaborated in more detail in the following sub-chapters. Geoprocessing of the SMK forest data was implemented in R programming environment to facilitate process automation, better documentation of the workflow, and reproducibility of the results. As the SMK forest data is nation-wide in coverage, the same code could also be used with just minor changes to produce forest ecosystem extent account, compliant with the EU ecosystem typology at level 2 (Eurostat 2023), for any other municipality in Finland.

Table 12. Pirkkala forest and urban green ecosystem typology levels 1-3, data source and maintenance class if applicable, and crosswalk to EU ET typology. ABC = Pirkkala Urban Green Maintenance classification, SMK = Finnish Forest Centre.

Ecosystem type, level 1	Ecosystem type, level 2	Ecosystem type, level 3	Data source	Crosswalk to EU ET typology
1. Settlements and other artificial areas	1.4 Urban greenspace	1.4.1 High-value urban parks (*Edustusviheralue*)	ABC (A1)	1.4.1
		1.4.2 Recreational urban parks (*Käyttöviheralue*)	ABC (A2)	1.4.1
		1.4.3 Protective/Buffer greenspace (*Käyttö- ja suojaviheralue*)	ABC (A3)	1.4.1
		1.4.4 Sports and recreation sites	ABC (E)	1.4.2
2. Cropland	2.1 Annual cropland	2.1.1 Cropland important for landscape (*Maisemapelto*)	ABC (B1)	2.1
3. Grassland	3.1 Sown pastures and fields (modified grassland)	3.1.1 Meadows and pastures important for landscape (*Maisemaniitty ja laidunalue*)	ABC (B3)	3.1
		3.1.2 Recreational meadows (*Käyttöniitty*)	ABC (B2)	3.1 (or 1.4.2)
		3.1.3 Open space (*Avoin alue*)	ABC (B4)	3.1
	3.2 Natural and semi-natural grassland	3.2.1 High nature value meadows (*Arvoniitty*)	ABC (B5)	3.2
4. Forests and woodlands	4.1 Broadleaved deciduous forest	4.1.1 Broadleaved deciduous forest	SMK	4.1
	4.2 Coniferous forest	4.2.1 Coniferous forest	SMK	4.2
	4.4 Mixed forest	4.4.1 Mixed forest	SMK	4.4
	4.5 Transitional forest and woodland shrub	4.5.1 Transitional forest and woodland shrub	SMK	4.5.1
	4.6 Other forests	4.6.1 Nearby urban/semiurban forests (*Lähimetsät*)	ABC (C1)	4
		4.6.2 Recreational forests (*Ulkoilu- ja virkistysmetsät*)	ABC (C2)	4
		4.6.3 Protective/Buffer forests (*Suojametsät*)	ABC (C3)	4

3.5.1.1 Processing and harmonizing forest extent data

SMK Forest stand database (retrieved 21.4.2022) was used as primary data source for the forest ETs of the extent account. The stands are delineated as polygon geometries having homogeneous characteristics for growth place, tree species and forest management, with average stand area being 1.4 hectares (SMK 2021). The stand geometries are accompanied with extensive set of variables collected either through field sampling, modelling or remote sensing, which can be used for further refining the forest ecosystem classification. Whenever forest management activities are done in a forest stand, the owner (or contractor) is responsible to send changed information back to SMK, keeping the database constantly up to date. In addition, these variables could also be used for compiling ecosystem condition accounts, although this was out of scope of our pilot.

The SMK Forest stand database covers majority of forest extent in Finland, including both privately and publicly owned forests. However, there are notable data gaps. It excludes forests which are not managed as commercial forestry for wood production due to various reasons – typical examples include forests under protection, forests where wood harvesting is not economically viable, forests used and maintained for recreation, and undeveloped/unmanaged plots where forests naturally regenerate. These types of forests can be rather common in urban and peri-urban municipalities. In order to follow the accounting principles of completeness, we looked into secondary data sources to cover also these forest types.

As secondary data, we used the **SMK Forest mask**, or "forests under commercial forestry and protected areas" dataset (own translation). We compiled the extent account using a layering approach: forest polygons not found in the primary data were extracted and processed from the secondary data, ensuring that no overlaps or double counting occurred. In other words, we prioritized the existing geometries of the SMK forest stand data and supplemented missing forest polygons from the secondary source. In many cases, a patch of forest existed in both data sources, but it was extracted only once, following the order of layering. Then, we included the municipal forests under maintenance classification into the extent account, and where there was an overlap with SMK forest data, the geometries of the municipal data were retained, and overlapping geometries were removed.

With this approach, we got as close as possible to full coverage of forest extent in Pirkkala, including: (1) forests under commercial forestry, (2) protected forests, (3) urban and peri-urban forests used mainly for recreation, and (4) miscellaneous other small forest patches used for example as protective or buffer zones.

3.5.1.2 Classifying the forest ecosystem types to level 2 of the EU typology

The proposed EU ecosystem typology (Eurostat 2023) has three levels. In case of forests and woodlands, the third level requires more detailed information on species composition, which was not available in the source data. Classifying forest ecosystems into level 2 of the EU Ecosystem Typology, however, was possible. Note that to keep the internal hierarchy in the typology logical, level 2 types were copied to level 3 with identical content, so in that sense the crosswalk to EU typology only works for level 2.

Classification to level 2 requires that each ecosystem asset, or polygon geometry, has the following variables available: (1) Proportion of coniferous and deciduous tree species, (2) Mean tree height, and (3) Canopy cover. For the SMK forest stands, the first two are pre-calculated by the data provider and can be derived from the database. For the forest polygons derived from secondary data, these variables can be calculated from the **Gridded forest resource data** (Hila). For both primary and secondary data, the **Canopy height model** was used to calculate canopy cover for each asset.

Finally, when all forest polygons are extracted and merged, and the necessary variables are calculated, we classified each forest polygon into one of the four possible forest ecosystem types at level 2 following the criteria set in the EU typology (Table 13). At the last stage, we combined the urban green maintenance class assets to the forest assets to derive the final Pirkkala ecosystem type map for year 2022 (Figure 16). Opening extents of each ET (in ha) at level 3 were summed and compiled to the Pirkkala extent account (Supplementary material 3).

Table 13. Pirkkala forest ecosystem types derived from SMK data and their classification criteria.

ET L3	Classification criteria
4.1.1 Broadleaved deciduous forest	Proportion of deciduous trees > 75 %
4.2.1 Coniferous forest	Proportion of coniferous trees > 75 %
4.4.1 Mixed forest	Proportion of deciduous trees < 75 % **AND** Proportion of coniferous trees < 75 %
4.5.1 Transitional forest and woodland shrub	Mean tree height < 5 m **OR** Canopy cover < 10 %

As mentioned earlier, forests that were under the municipal maintenance classification could not be cross walked to the EU typology, and they were treated separately as ET 4.6 (Other forest). An alternative treatment, which would have ensured compatibility to the EU typology, would be to use only the polygon geometries of the maintenance classes, and then assign those assets to ecosystem types 4.1 to 4.5 based on the variables extracted from SMK Gridded forest resource data and Canopy height model. However, we did not do this as we wanted to preserve the original maintenance classifications in the accounts.

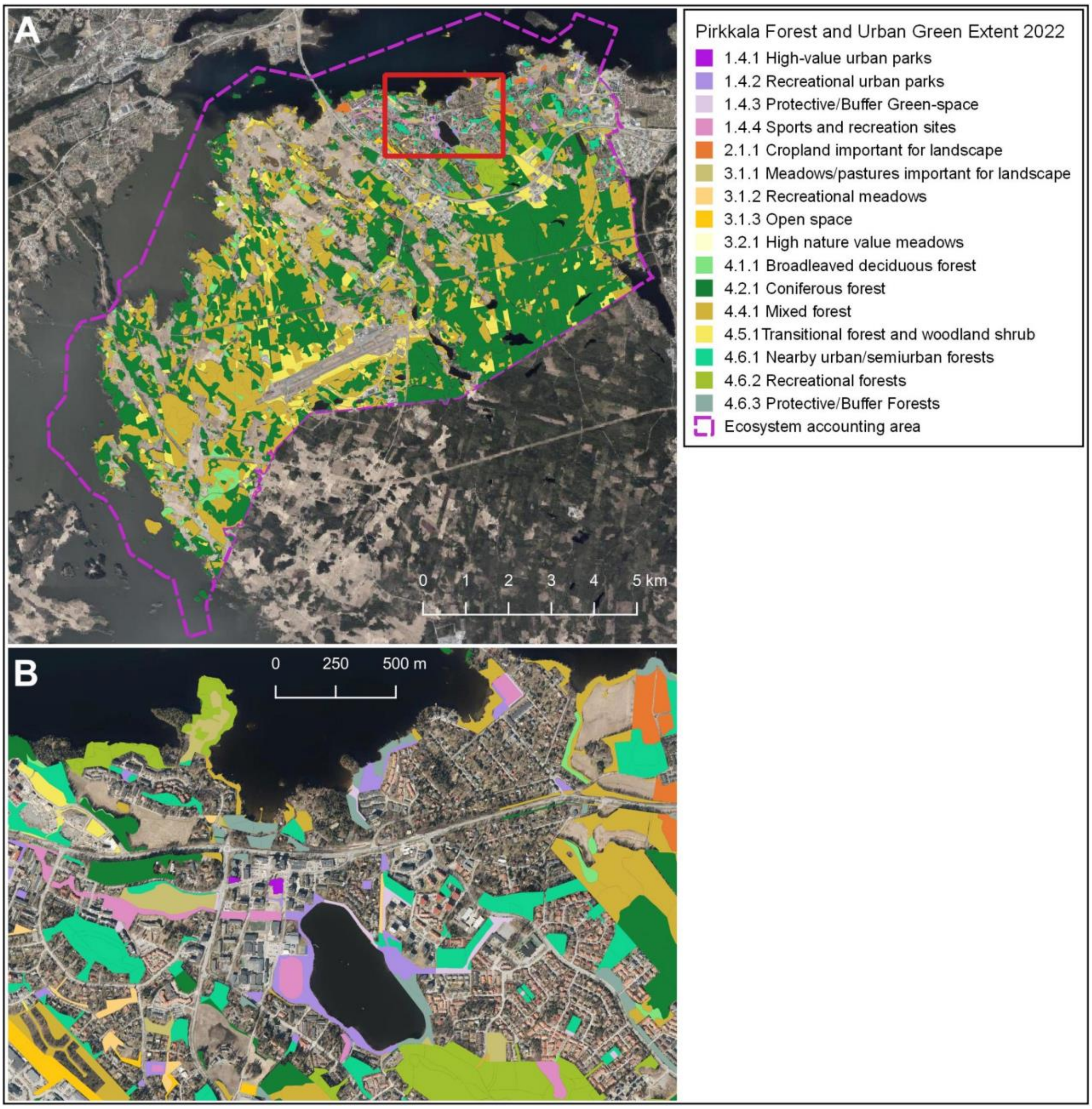

Figure 16. Pirkkala Forest and Urban Green Ecosystem Extent in 2022 (A), and close-up (red rectangle) to Pirkkala urban center (B). Background aerial photographs by National Land Survey of Finland.

3.5.2 Tampere Ecosystem Extent Account

In Tampere, stormwater management was highlighted as one of the critical use cases where urban ecosystem accounting methods could provide new insights on the physical and monetary value of the flood mitigation ecosystem service provided by urban green. As a prerequisite, modelling the supply and use of this service required wall-to-wall mapping of all ecosystem assets from the whole watershed where Tampere municipality is situated – i.e. ecosystem accounting area crossed the municipal boundary.

First, suitability of available datasets to model the extent was investigated. No suitable habitat or ecosystem type maps existed for the whole accounting area, which made it necessary to use land cover as a proxy for ET. These included the vector-based Land Cover map and urban green maintenance classes produced by the city of Tampere at 1:4000 scale, raster-based national CORINE Land Cover (CLC) high-resolution accounting layer time-series, and vector-based Topographic database by NLS. From these options, we assessed the CLC to be the most suitable for our piloting purpose, for the following reasons. First, it might have been tempting to use the vector-based options, which had much higher spatial detail than CLC. However, CLC provides systematic and comprehensive coverage of all ecosystem types throughout the watershed, and its uncertainties have been assessed with independent field observations. It means we can expect more robust results from modelling the flood mitigation ecosystem service supply and use by using CLC. Second, harmonized and comparable CLC accounting layers were also available for different time-periods, which made it possible to track changes in the extent (not only opening, but also closing extent) and changes in the supply of ecosystem services. Third, the national CLC time-series will most likely be the main source of information to compile extent accounts at national level, so testing its suitability first at municipal scale was very motivating.

To guarantee thematic accuracy and to avoid mapping false changes between the opening (2012) and closing (2018) years of the account, we used a harmonized 'accounting-layer' version of the CLC time series produced by Syke. Harmonization was done using a backdating method originally developed for studying the usability of CLC datasets in LULUCF (Land use, land-use change and forestry) reporting. The backdating method uses the newest CLC dataset of 2018 and the CLC change layers to reproduce and harmonize the older CLC status layers. The change layers have been modified to minimize artificial or unrealistic changes caused by misclassifications of the CLC status layers with methods such as omitting the smallest groups of change pixels (smaller than the minimum mapping unit of 0.5 hectares), buffering areas and manual digitizing.

The backdated CLC layers of 2012 and 2018 were further reclassified from the 34 land cover types that occurred in the EAA into 17 ETs. In similar fashion with the other municipalities, we attempted to crosswalk the ETs to the proposed EU typology as much as feasible. Since this pilot extent account was compiled for the purpose of modelling the supply of flood mitigation, it guided us to merge certain ETs which were similar in their natural hydrological processes and stormwater retention properties. This was done for level 1 types cropland and pasture, as well as rivers and lakes, which were merged. Out of the 17 ETs in the Tampere typology, eight could be cross walked to level 2 and seven to level 3 of the EU typology (Table 14). Ecosystem type maps of Tampere for opening (2012) and closing extent (2018) are presented in Figure 17 and Figure 18.

*Table 14. Tampere ecosystem typology, levels 1-3, and crosswalk to Finnish CLC and EU ET typology. * Commercial and industrial areas are listed in the EU typology as level 3 subtypes of 1.1 and 1.2 but in Finnish CLC they are mapped separate of settlement areas.*

Ecosystem type, level 1	Ecosystem type, level 2	Ecosystem type, level 3	Finnish CLC crosswalk	EU ET typology crosswalk
1. Settlements and other artificial areas	1.1 Continuous settlement area	1.1.1 Continuous settlement area	1.1.1.1	1.1.1
	1.2 Discontinuous settlement area	1.2.1 Discontinuous settlement area	1.1.2.1	1.1.2
	1.3 Infrastructure	1.3.1 Infrastructure	1.2.2.1, 1.2.3.1, 1.2.4.1, 1.3.1.1, 1.3.1.2, 1.3.2.1, 1.3.3.1	1.3
	1.4 Urban greenspace	1.4.1 Parks	1.4.1.1	1.4.1
		1.4.2 Sports and recreation sites	1.4.2.2	1.4.2
		1.4.3 Summer cottages	1.4.2.1	1.4.3
	1.5 Commercial and industrial areas*	1.5.1 Commercial and industrial areas	1.2.1.1, 1.2.2.1	1.5
2. Cropland and pasture	2.1 Cropland and pasture	2.1.1 Cropland and pasture	2.1.1.1, 2.2.2.1, 2.3.1.1, 2.3.1.2, 2.4.3.1, 2.4.4.1	2, 3
4. Forests and woodlands	4.1 Broadleaved deciduous forest	4.1.1 Broadleaved deciduous forest	3.1.1.1, 3.1.1.2	4.1
	4.2 Coniferous forest	4.2.1 Coniferous forest	3.1.2.1, 3.1.2.2, 3.1.2.3	4.2
	4.4 Mixed forest	4.4.1 Mixed forest	3.1.3.1, 3.1.3.2, 3.1.3.3	4.4
	4.5 Transitional forest and woodland shrub	4.5.1 Transitional forest and woodland shrub	3.2.4.1, 3.2.4.2, 3.2.4.3, 3.2.4.4, 3.2.4.6	4.5.1
6. Sparsely vegetated ecosystems	6.1 Bare rock	6.1.1 Bare rock	3.3.2.1	6.1.1
7. Inland marshes	7.1 Inland marshes on mineral soil	7.1.1 Inland marshes on mineral soil	4.1.1.1	7.1
	7.2 Mires, bogs and fens	7.2.1 Mires, bogs and fens	4.1.2.1	7.2
8. Rivers and lakes	8.1 Rivers and lakes	8.1.1 Rivers and lakes	5.1.1.1, 5.1.2.1	8, 9
11. Coastal beaches, dunes and wetlands	11.2 Coastal dunes, beaches and sandy and muddy shores	11.2 Coastal dunes, beaches and sandy and muddy shores	3.3.1.1	11.2

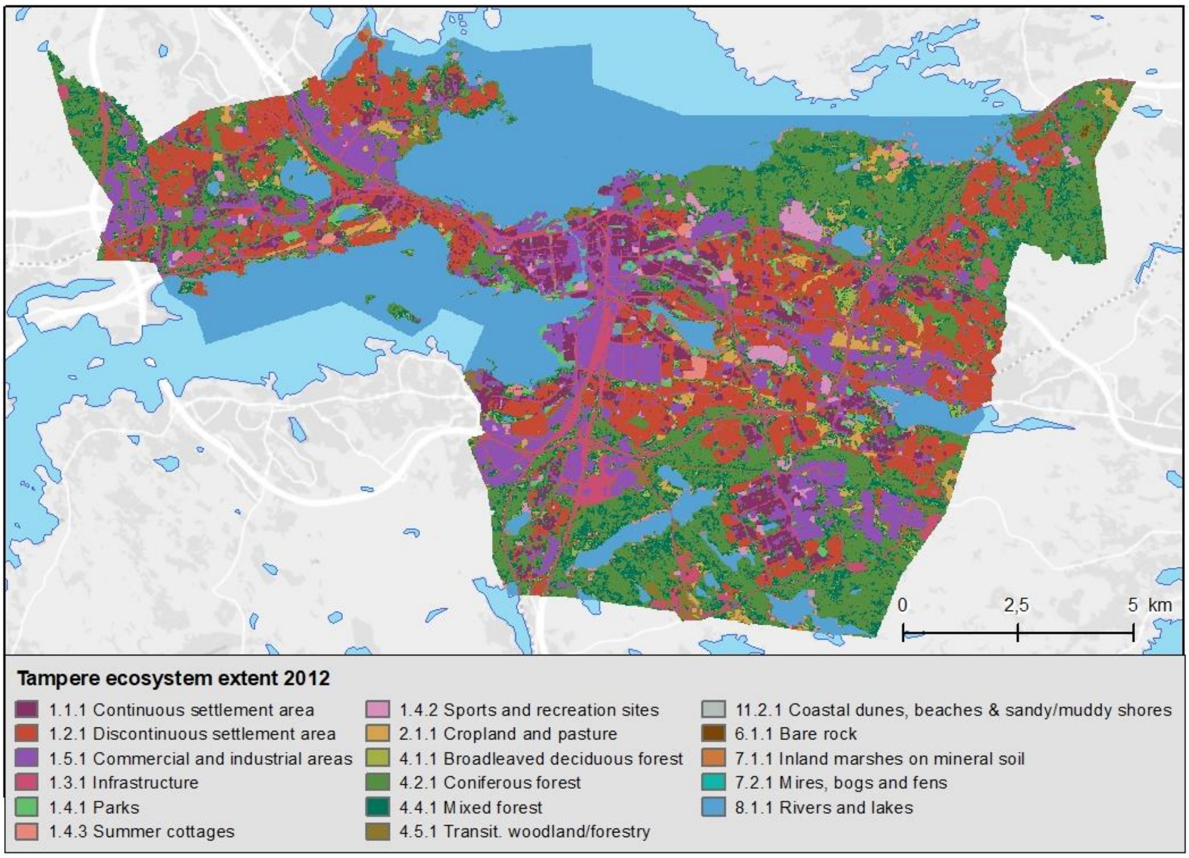

Figure 17. Tampere ecosystem opening extent in 2012. Background map: ESRI/MML, SYKE (Ranta250).

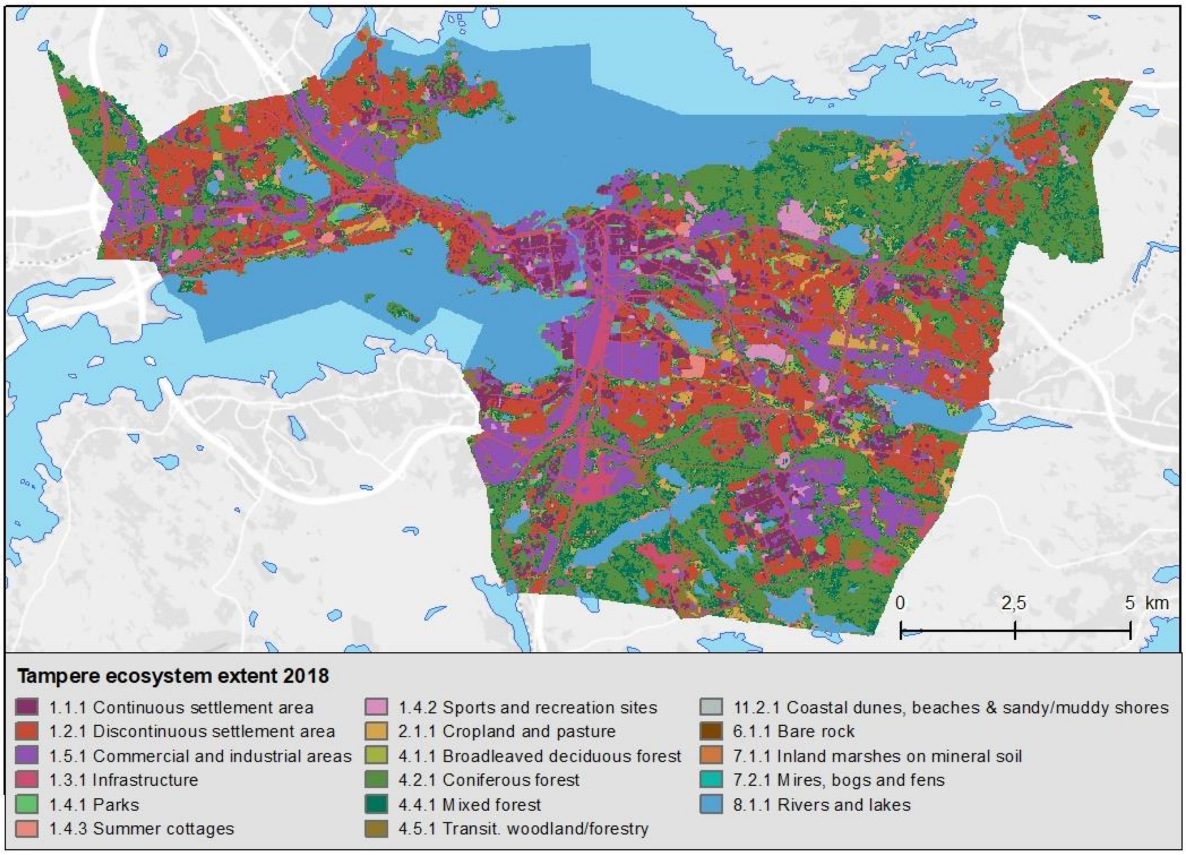

Figure 18. Tampere ecosystem closing extent in 2018. Background map: ESRI/MML, SYKE (Ranta250).

Simplifying the ecosystem typology and focusing on ETs that are relevant for ecosystem services supply also facilitated the interpretability of the extent account (additions and reductions and the change matrix). A simple reclassification can also potentially correct uncertainty and improve the accuracy of LULC data (Alfieri et al. 2007). The downside of this approach is that thematic detail that could be valuable for other applications of urban EA is lost. For example, infrastructure could be modelled at seven different ETs at level 3 instead of one, and commercial and industrial ETs could be separated.

The reclassified and backdated CLC layers from 2012 and 2018, and the typology at level 3, were used for the opening and closing extents, respectively. Cross-tabulation between the two was calculated to derive pixel counts for every ecosystem conversion, which were then converted to hectares to populate the ET change matrix and the ecosystem extent account table (Supplementary material 4) following SEEA EA standard (UN 2021). Separately accounting for managed and unmanaged expansions or reductions was not possible as this information was not available.

3.5.2.1 **Ecosystem type conversions**

The Tampere ecosystem extent account consists of ET maps for the years 2012 (Figure 17) and 2018 (Figure 18), the ET change matrix with detailed from class-to-class information (Supplementary material 4), and the actual accounting table describing in hectares the opening and closing extent, the additions and reductions, and the net change in the extent of each ET (Supplementary material 4). The ecosystem extent account provides an overall estimate of the turnover of pervious and impervious ecosystem types, which is important for the assessment of changes in the potential supply of flood mitigation ecosystem service.

From 2012 to 2018, ecosystem types characterized by pervious surfaces (cropland, pasture and different types of forests) lost a total of 100 hectares of extent (0.8 % of total land extent of the EAA) to impervious or semi-impervious ecosystem types (continuous and discontinuous urban fabric, commercial and industrial units, sport and leisure areas).

3.5.3 Helsinki Urban Green Ecosystem Extent Account

In the Helsinki pilot, we tested the feasibility of harmonizing available spatial datasets for accounting the extent of urban green, which would form the basis for compiling recreation ecosystem service accounts in both physical and monetary terms. Municipal boundary was used as ecosystem accounting area.

In our assessment of existing spatial datasets we found out that Helsinki's Register of Public Areas (YLRE), which includes the urban green space maintenance classes, showed good potential for compiling the pilot account. As the YLRE only contains assets owned by the

Municipality, the remaining urban green, cropland as well as forest and woodland assets under different ownership had to be included from other data sources.

For the case of forests and woodlands, SMK data was our first choice, as it had worked well for Pirkkala. Unfortunately, it turned out that SMK forest stand data coverage was patchy for Helsinki (as there is hardly any commercial forestry in the capital), and it would have to be supplemented by secondary data sources on forests. On the other hand, we still aimed to cover the missing urban green and cropland, which SMK data does not have. Merging and harmonizing too many datasets from different sources to create an extent account is not the most feasible approach, adding unnecessary uncertainties to the accounts and makes it more difficult to reproduce. For these reasons, we chose to experiment the use of Urban Atlas (UA) data produced by Copernicus Land Monitoring Service. It is modelled in polygon format so merging and harmonizing it with YLRE maintenance class data was straightforward.

The YLRE Register of Public Areas has very fine-scaled information on urban green assets compared to Pirkkala's urban green maintenance classes, allowing experimentations with even more detailed ecosystem typologies. For example, a single urban park (such as Töölönlahti park shown in Figure 14) can consist of several hundreds of small polygons which can belong to different maintenance classes and can include also impervious surfaces such as asphalt or gravel.

The proposed typology of Helsinki Urban Green ecosystems (Table 15) has four levels, and only partial alignment with Eurostat's proposed EU typology was possible. The typology and ecosystem extent account have the following characteristics:

- From the first ET at level 1 - *Settlements and other artificial areas* – we included the urban green space owned by the municipality from YLRE, and remaining green space was collected from UA. Three urban park ETs at level 4, five sports and recreation sites ETs and one other urban green ET could be distinguished based on available data.
- From the second ET at level 1 – *Cropland* – we included one ET at level 4 for cropland owned by the municipality from YLRE, and remaining cropland from UA was put into one ET at level 4.
- From the third ET at level 1 – *Grassland* – we included three modified grassland ETs and one semi-natural grassland ET at level 4. UA data did not have grasslands so only YLRE was used.
- From the fourth ET at level 1 – *Forests and Woodlands* – we included five ETs at level 4 consisting of municipality-owned and maintenance-classified forests from YLRE. The remaining forests were added as an additional ET (Other forests) which consisted of forests owned by municipality but NOT maintenance-classified, and the remaining forests under different ownership found from UA.
- From the seventh ET at level 1 – *Inland wetlands* – we included reedbeds owned by municipality, which is a separate maintenance class in YLRE. UA did not have reedbeds separately mapped.

Table 15. Helsinki urban green ecosystem typology, levels 1-4, data source and maintenance class if applicable, and crosswalk to EU ET typology. YLRE = Helsinki Register of public areas, UA = Urban Atlas.

Ecosystem type, level 1	Ecosystem type, level 2	Ecosystem type, level 3	Ecosystem type, level 4	Data source	EU typology crosswalk
1. Settlements and other artificial areas	1.4 Urban greenspace	1.4.1 Parks	1.4.1.1 High-value urban parks (*Edustusviheralue*)	YLRE (A1)	1.4.1
			1.4.1.2 Recreational urban parks (*Käyttöviheralue*)	YLRE (A2)	1.4.1
			1.4.1.3 Protective/Buffer green space (*Käyttö- ja suojaviheralue*)	YLRE (A3)	1.4.1
		1.4.2 Sports and recreation sites	1.4.2.1 Camping sites	YLRE (n/a)	1.4.2
			1.4.2.2 Sport sites and playgrounds	YLRE (n/a)	1.4.2
			1.4.2.3 Allotment and community gardens	YLRE (n/a)	1.4.2
			1.4.2.4 Bathing beaches	YLRE (n/a)	1.4.2
			1.4.2.5 Recreational meadows	YLRE (B2)	1.4.2 (or 3.1)
		1.4.3 Other urban green	1.4.3.1 Other urban green	UA	1.4
2. Cropland	2.1 Annual cropland	2.1.1 Cropland important for landscape (*Maisemapelto*)	2.1.1.1 Cropland important for landscape	YLRE (B1)	2.1
		2.1.2 Other cropland	2.1.2.1 Other cropland	YLRE (n/a), UA	2.1
3. Grassland	3.1 Sown pastures and fields (modified grassland)	3.1.1 Modified meadows, pastures and lawns	3.1.1.1 Meadows and pastures important for landscape	YLRE (B3)	3.1
			3.1.1.2 Open space (*Avoin alue*)	YLRE (B4)	3.1
			3.1.1.3 Other lawns and meadows	YLRE (n/a)	3.1
	3.2 Natural and semi-natural grassland	3.2.1 High nature value meadows (*Arvoniitty*)	3.2.1.1 High nature value meadows	YLRE (B5)	3.2
4. Forests and woodlands	4.1 Nearby urban/semi-urban forests (*Lähimetsät*)	4.1.1 Nearby urban/semiurban forests	4.1.1.1 Nearby urban/semiurban forests	YLRE (C1, C1.1, C1.2)	4
	4.2 Recreational forests (*Ulkoilu- ja virkistysmetsät*)	4.2.1 Recreational forests	4.2.1.1 Recreational forests	YLRE (C2, C2.1)	4
	4.3 Protective/Buffer forests (*Suojametsät*)	4.3.1 Protective/Buffer forests	4.3.1.1 Protective/Buffer forests	YLRE (C3)	4
	4.4 Commercial forests (*Talousmetsät*)	4.4.1 Commercial forests	4.4.1.1 Commercial forests	YLRE (C4)	4
	4.5 High nature-value forests (*Arvometsät*)	4.5.1 High nature-value forests	4.5.1.1 High nature-value forests	YLRE (C1)	4
	4.6 Other forests	4.6.1 Other forests	4.6.1.1 Other forests	YLRE (n/a), UA	4
7. Inland wetlands	7.1 Inland marshes on mineral soil	7.1.1 Reedbeds	7.1.1.1 Reedbeds	YLRE (B6)	7.1.1

The geoprocessing steps to compile the extent account were document and automated with QGIS Graphical Modeler scripts. From YLRE, we firstly included all ecosystem assets (polygons) which had a maintenance class (Ax, Bx or Cx) in the register. After getting more familiar with the data, we found out that there was a considerable share of urban green assets in YLRE that were not in any maintenance class, but we found useful to include in the extent. These were identified and interpreted to be urban green assets based on other attribute data in the register, such as purpose of use, subtype or park name, and by comparing the assets to aerial photographs and topographic maps.

After this step, geoprocessing tools were used to include those urban green, cropland and forest assets from UA that were not covered in YLRE. Here, we followed the same principles as we did with Pirkkala to avoid overlaps. Lastly, YLRE and UA assets were merged and classified into ecosystem types (Figure 19) and opening extent (2022) of each ecosystem type was calculated in hectares and the extent account was compiled (Supplementary material 5).

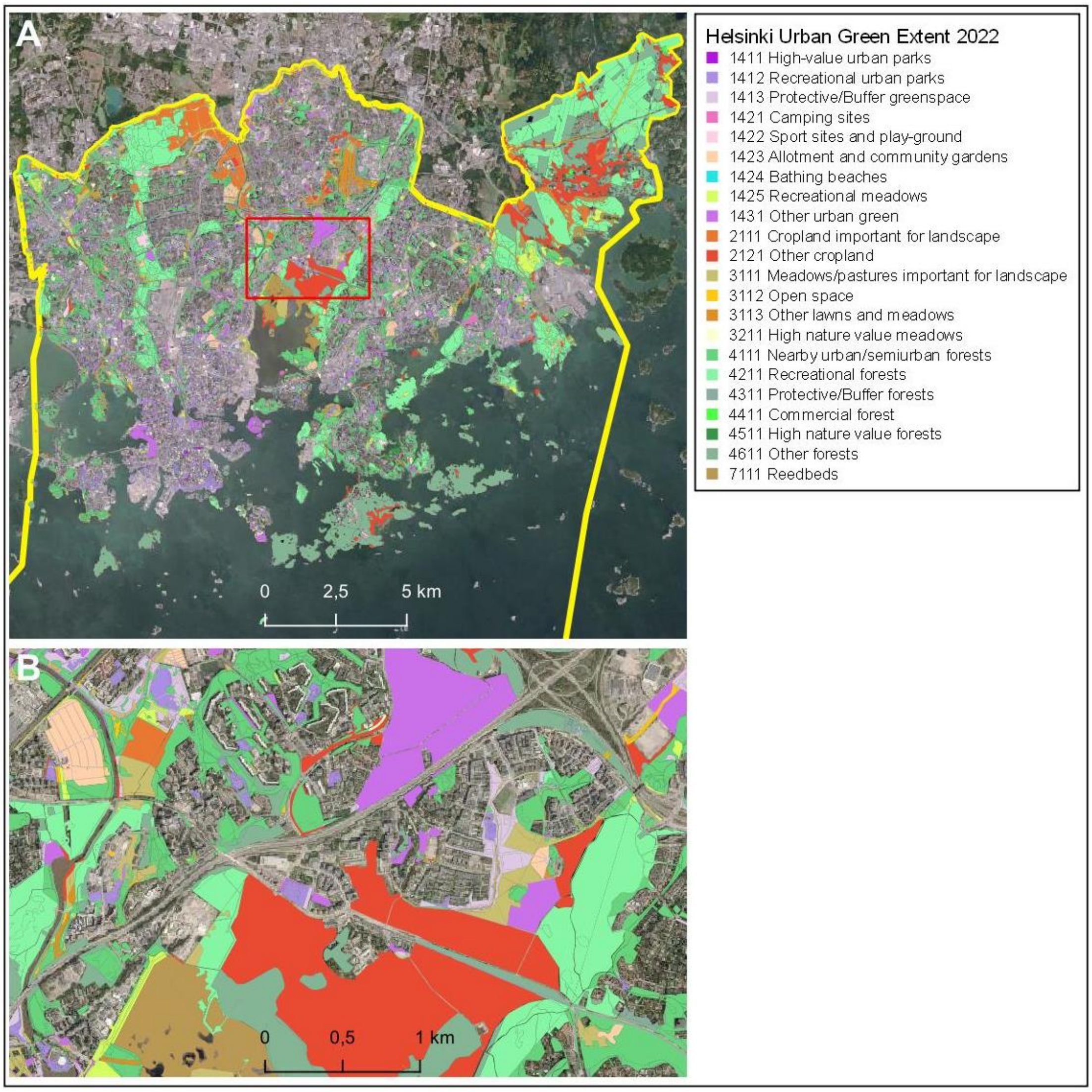

Figure 19. Helsinki Urban Green Ecosystem Extent in 2022 (A), and close-up (red rectangle) to Pihlajamäki/Viikki area (B). Background aerial photographs by National Land Survey of Finland.

3.6 Testing and piloting ecosystem service supply and use accounts

3.6.1 Pirkkala supply and use accounts of educational and recreational ecosystem services

Educational services and recreational services were selected as the focused services in the Pirkkala pilot. Two surveys were conducted separately to collect the required data for quantification of each service. This section will first explain the methods and results of the educational survey and the valuation of the educational services, the methods and results of the recreational survey, and then explain how to compile the ecosystem services supply and use accounts based on the survey results.

3.6.1.1 Survey of educational visiting to nature

To quantify the educational ecosystem service provided by urban green and forest areas in Pirkkala municipality, a survey was sent to teachers or managers of the day-care centres and primary and secondary schools in Pirkkala municipality by our municipality collaborators. The survey was conducted in Finnish on the map survey platform ArcGIS Survey123, between autumn 2021-spring 2022.

There are eight school units in Pirkkala municipality: six primary school units with grades 0-6 (maximum, the smallest one only has 0-2 grades), one unified school (0-9 grades), and one secondary school (7-9 grade). In total there are 13 day-care centres in Pirkkala: 11 are run by the municipality and two by private companies. Four out of the eight school units replied to the survey, which covered 36,3% of students in Pirkkala (Table 16). Seven out of 13 day-care centres replied to the survey. The total number of children enrolled in day-care centres for the entire Pirkkala is unknown. However, based on the survey, the scale of most day-care centres is quite close. Therefore, with an assumption that roughly half of the children in Pirkkala were covered in the surveyed day-care centres, 36,3% of students and 50% of children were used to quantify the educational services at the municipality level from the survey.

*Table 16. Summary of the basic information and survey results of day-care centres and schools in Pirkkala. * When the schools are from the same organization but located at different places, they are considered different units. ** The ranges depend on the chosen options of visiting frequency (e.g., 3-6 times in the past 12 months, a few times a month (2-3 times per month)) in the survey. *** The ranges depend on the chosen options of visiting frequency and number of students in each school/day-care centre. Underlined: The values that are used for compiling supply and use account.*

	Schools	Day-care centres
Total Pirkkala municipality		
No. of units*	8 (6 primary + 1 unified +1 middle)	13 (public + private)
No. of students / children covered	3 156	Unknown
Survey summary		
No. of units respond the survey	4 (all primary schools)	7 (all public day-care centres)
No. of students / children covered	1 146 (36,3%)	582
Yearly no. of visits based on the survey**	5 268 - 6 600	33 241 - 42 646
Yearly visiting time (in hours) based on the survey**	7 812 - 9 701	80 197 - 117 222
Yearly no. of visits per person***	2,9 - 11,8	22.4 - 111,4
Average visiting hours per person per year**	6,8 - 8,5	138– 201
Estimation from survey to Pirkkala level using 36,3% and 50%		
Yearly no. of visits, approximate for Pirkkala	14 508 - 18 175	66 481 – 85 292
	80 989 - 103 467	
Yearly visiting hours, approximate for Pirkkala	21 515 - 26 717	160 933 - 253 846
	181 908 - 280 563	

The English version of the survey form can be seen in Supplementary material 6. The survey included three sections: The first section asked for the basic information about day-care centres/schools, including types (school or day-care centre), name of the unit, opening months and numbers of children/students in total of the unit etc. By asking "Are you answering the survey for the entire unit or your own group", we made it possible that it would be enough for one teacher to answer the survey on behalf of the whole unit. The name of the school helped to identify if there is more than one teacher who replied to the questionaries. This information, together with the marked points and the visiting frequency per marked point in the section of the survey, determined how to aggregate the number of visits per year for each school/day-care centre and helped to calculate the number of visits per student.

In the second section of the survey, the respondents could mark several points on the map to indicate the places in nature where they brought students/children during the past 12 months. For each marked point, follow-up questions were asked, including frequency of visits, average time spent, and the activities done at the location. The average number of students that attended the visit was also asked. The supplementary questions in the third section of the survey included whether the marked point covered all the visited places and how did COVID-19 influence the visits.

The survey results show that COVID-19 had a negative influence in terms of shorter openings for some units. Some units, however, increased the frequency of visits during the opening of the school/day-care centres due to COVID-19. Two schools and five day-care centres noted that their marked places were not comprehensive. Therefore, we can consider that the estimation of the education services based on this survey can be considered as the minimum level of the services provided by the urban green and forest areas in Pirkkala.

The number of visits is suggested as the physical terms of educational ecosystem service (UN 2021), and visiting time is needed for some valuation approaches (Oras et al. 2019). Therefore, both the number of visits and visiting time are regarded as the required indicators that should be compiled into the supply and use account. The surveyed visiting numbers and times were aggregated from 65 marked places of visit (Figure 20). The value of aggregated visiting numbers and times, the average of both, and the estimation of which at Pirkkala level are summarized in Table 16. The lower bound of the aggregated number of visits and visiting time (underlined in Table 16) were used to compile the supply and use account in physical terms. These total levels of educational services in physical terms (number of visits and visiting time) are allocated as the use of the educational services by the education sector in the society (see Pirkkala supply and use table in Supplementary material 3).

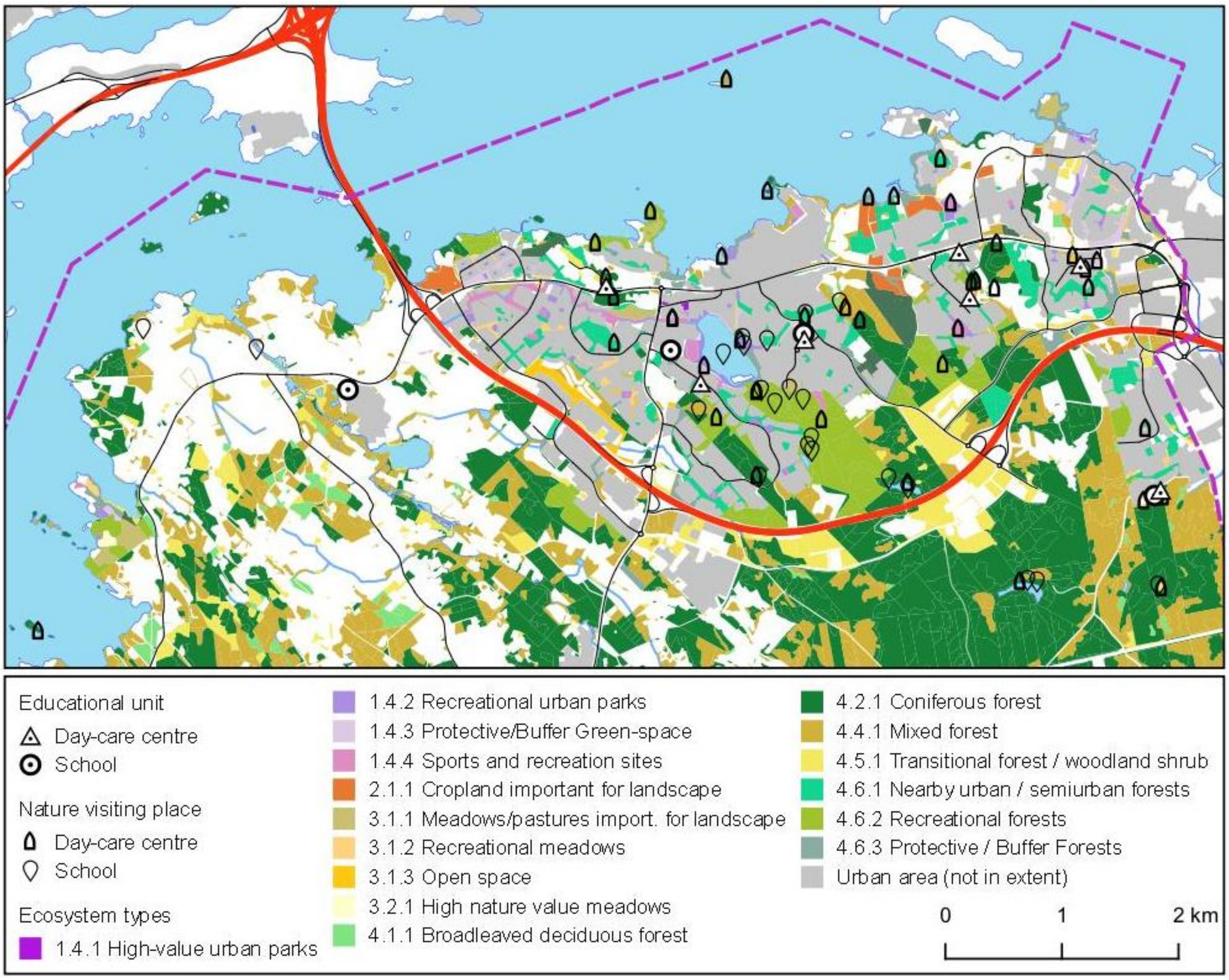

Figure 20. Location of educational units and the places in nature they have visited based on the Pirkkala educational survey. Background map layers (urban area, roads, rivers and lakes) from NLS Topographic database.

3.6.1.2 **Valuation of educational services**

The educational services that are measured by the visits in nature from the schools and day-care centres do not have a directly observable market price as they are embedded in the program of schools/day-care centres or provided as public a good with support and free of charge. SEEA EA (UN 2021) recommend that the market prices of similar products can be used as the price of the services that do not have a directly observable market price. In Finland, outdoor nature activities or similar environmental education programs can also be provided, for schools as a group or for an individual child to attend, by the environmental education network, local government, private natural and environmental educational centres or companies, and nature-related associations. Some of these organizations provide on their websites the price of similar programs/activities which can be considered as representative products.

During this pilot, we collected the price of 17 different environmental education programs or outdoor nature activities from three different organizations. The selection of the programs or activities was based on the activities mentioned in the educational survey and considered only one-day programs to align with the visiting hours answered in the educational survey (see

Table 17). The information on programs/activities also provided the time length of each program, and the maximum number of participants if the price is for a group. Therefore, we calculated the price per student per hour for the collected 17 activities. After the calculation, the price per student per hour ranges between 1,3-14,3 EUR, with an average of 3,53 EUR.

Table 17. Comparison of educational survey data and environmental/educational activity provided by the organizations collected for valuation

	Educational survey	Price data collection
Activity done during the nature visits/from the program	Learning of forest biology (berries, mushrooms or nature in general), bog biology, aquatic biology or some other environmental educational program, exploring the nature grove and birdwatching, different kinds of exercise (walking, hiking, frisbee golf, climbing, geocaching, fishing, sledge-riding, skiing, skating, etc.), campfire cooking, or just staying, resting, playing and picknicking in the nature etc.	Educational trip to the lake and forest for learning aquatic forest biology, outdoor game, hiking, natural walking, campfire cooking, fishing, natural exploration, kick-sledge, snowshoes hiking, climbing, etc.
Average number of visiting hours per trip/length of the activity provided by the organizations	0,5-12 hr	1-8 hr, depending on the activity type
Data source	The open question about what activities were done at the marked visiting place in the survey	Visit Lahti: Link Luonto-Liitto (a nature hobby and environmental protection organization): Link Youth Centre Marttinen: Link

Oras et al. (2019) also used similar data, the revenue from those providing the nature education service, in their expenditure-based approach and they discuss two ways to use such data. First, using the expenditures of providing nature education programs as the value of nature educational service, with an assumption that expenditures will be covered by the revenue of the educational products. So, the revenue (or price in the case of this pilot) can be the maximum value of the educational services. Second, only the profit of the educational program should be considered as the value to be allocated to nature. For the case of this pilot, this means that the cost component needs to be excluded from the price. The second one aligns with the resource rent approach from SEEA (UN 2021); thus, this pilot also follows the second one.

However, the cost information from those programs is hard to access, and it can be various a lot depending on if the equipment is needed, or whether it includes food or not. For a rough estimation, we used only the programs that do not need the equipment, with an assumption that the programme only needs to pay the wages for the teacher/instructor of the programme. Based on the available data with an assumption case shown in Table 18, the unit resource rent was estimated between 0%-60% of the price. With a lower number of students per course or a shorter time, the resource rent could be negative, while more students and a longer program can increase the percentage of the resource rent. In the case of Oras et al (2019), 17% of the revenue is the average profit (or resource rent) in Estonia.

Table 18. An assumption case to estimate the possible ranges of the resource rent for educational services

	EUR/hour/student	Assumption	Source
Price	1.3-2.6	-	8 from the 17 collected program/activity that probably not need the equipment
Cost	1.06-1.3	€20/h + €10 for 30 min preparation, for a 1,5 hr course, for 20-25 students	Salary costs of a part-time environmental educator to the school from Luonto-Liitto: link

Negative or no resource rent is a possible case, implying that the value of nature in providing educational services is underestimated. However, as the cost data was not comprehensively explored in the pilot, it might not be meaningful to demonstrate the negative results. Therefore, we use 17 % and 60 % together with the average 3.53 EUR/student/hour from the price of 17 collected programs to demonstrate the supply and use accounts. With these numbers, the estimated unit value of the educational service is 0.6 and 2.1 EUR/student/hour respectively, which then were multiplied by the physical term, visiting time, from the survey to quantify the value of educational services.

3.6.1.3 **Survey of recreational visiting to nature**

The recreational survey was conducted in autumn 2022 to quantify the recreational services in Pirkkala. The survey was conducted in Finnish, on a map survey platform, Harava. The survey was spread by collaboration with Pirkkala municipality, adverting on the municipality's website and local newspapers. The survey targeted people who have made recreational visits in Pirkkala, including visits made by people residing outside Pirkkala municipality. Like in the educational survey, the recreational visiting locations during the past 12 months were asked, followed by questions of frequency of visits in different seasons, time spent, and activities done. Also, information used for estimating the travel costs were included. The English version of the survey can be seen in Supplementary material 7.

By the end of the survey, the survey link was opened over 480 times; but we only received 77 submitted responses with 377 marked visiting places (Figure 21). As the sample was not statistically representative, such small number of responses is not suitable to derive the entire value of Pirkkala. To find out the reason of the low response rate, a careful review of feedback from the respondents was done.

The main reason reflected from the response was that the map survey platform was very hard to operate, especially if the survey was filled with mobile phone. The difficulty of navigating and operating the map was not only reflected in the submitted answers, but it also became apparent through the respondents' direct communication to the researcher. In addition, based on the feedback, the difficulty of using the map survey platform also caused many respondents to mark the visiting places at wrong locations, and in some cases even made the respondent to give up adding more points and submit the answers incomplete.

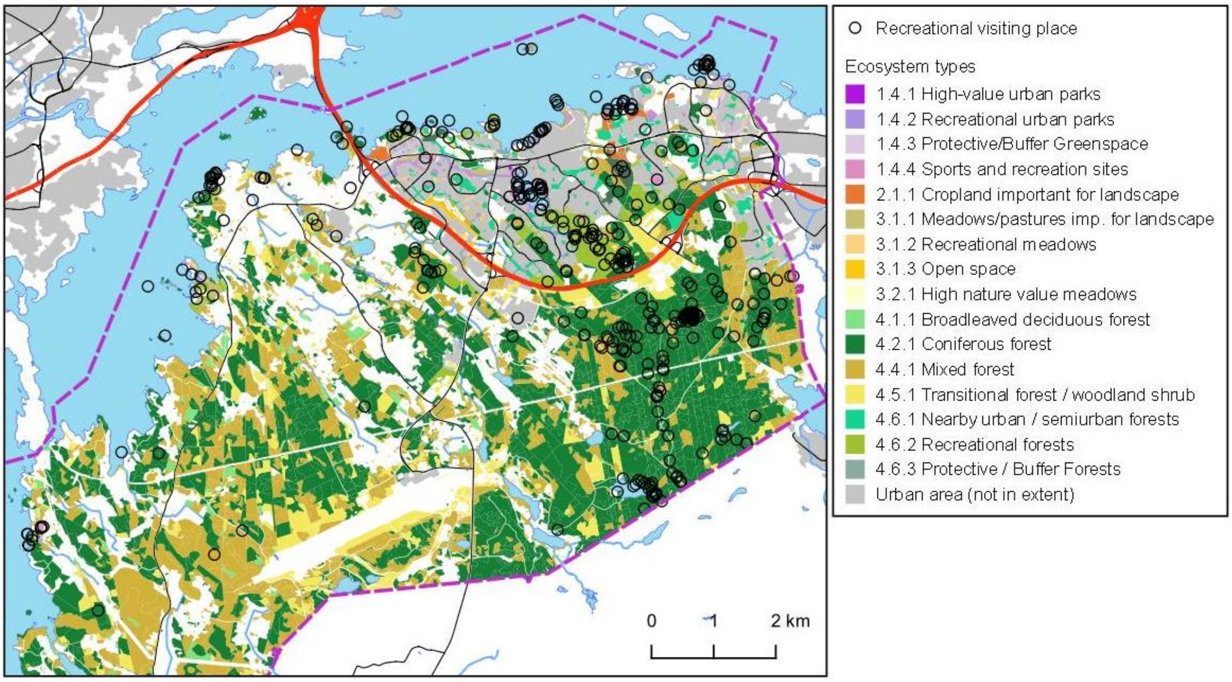

Figure 21. Location of nature visiting places from the Pirkkala recreational survey. Background map layers (urban area, roads, rivers and lakes) from NLS Topographic database.

Due to these technical issues and limited time, we decided to take this survey as a preliminary test of implementing a recreational survey for accounting purpose and did not derive the survey results to estimate the recreational service for entire Pirkkala EAA. Therefore, in this pilot we only compiled the survey numbers in the physical supply and use accounts to demonstrate how the accounts would look like. Also, the value of recreational services was not estimated, due to the concerns of high uncertainty of the physical terms and was not included in the monetary supply and use account.

3.6.1.4 **Compiling supply and use account by linking educational visits and recreational visits to extent account**

Both educational and recreational surveys included the questions of marking the nature visiting places on the map (Figure 20 and Figure 21). Therefore, we allocated the number of visits and visiting time to different ecosystem types of Pirkkala (at level 3) through overlaying the marked points and the ecosystem extent types, and then compiled the supply accounts according to the allocated numbers in different ETs. In addition to the ecosystem types included in the Pirkkala ecosystem forest and urban green extent account, rivers and lakes (urban bluespace) are also included as these are also common visiting ecosystem for both educational and recreational purposes.

Accuracy of marking points in the map survey is influenced by how close the respondent zooms into the map when marking the nature visiting point, and this can potentially cause unintended ecosystem types to be linked. For the case of educational survey, the marked location was checked and corrected if it is needed, by comparing the marked location, the open answers on the activity from respondents, and local knowledge from municipality staffs. This kind of checking is only doable with small data and close collaboration with local stakeholder (municipality in this case). Within the 66 marked points, 49 were identified as accurate, nine were identified probably accurate or probably refer to multiple points in that larger areas, seven were adjusted to the possible nearby visiting places, and one was excluded for locating outside the EAA. After revising, three points which were identified as "probably refer to multiple points in those larger areas" were unable to link to specific ecosystem type in the ecosystem extent account. Those points were marked at the places belonging to other ecosystem types (e.g., a settlement area, even though it is able to identify is in nature based on their open questions of the visiting activity), and thus the visiting to those points were classified to "others" in the supply and use account.

For the recreational survey, there are much more data points and likely have more error due to the issues mentioned in chapter 3.6.1.3. Such checking was not implantable within this pilot project, which is another reason we only demonstrate the recreational results with survey numbers. There were 11 out 377 marked points unable to link to specific ecosystem type in the ecosystem extent account, and thus and thus the visiting to those points were classified to "others" in the supply and use account. The allocation of the services to different ecosystem types can be seen in the supply table (Supplementary material 3). In the user account, the users are education sector and households for educational and recreational ecosystem services, respectively.

3.6.2 Tampere supply and use account for flood mitigation services

3.6.2.1 Modelling the flood mitigation ecosystem service with InVEST

The flood mitigation service provided by urban green and other land types was one of the selected services for the city of Tampere. During the first year we tested the use of the InVEST modelling tool to estimate the flood mitigation service in physical terms. During the second year, the model was refined and validated with available empirical data to have better estimation of the services in physical terms. The estimated results were further combined with the valuation approach and economic data that has been explored, which is avoided damage cost method with Finnish flood damage cost function, to estimate the value of the services and compile the supply and use accounts in the monetary term.

The InVEST model provided results on both the flow retention and volume of surface runoff (m^3). The model quantified the flood mitigation service provided by the green areas in terms of runoff retention index per pixel (see Figure 22 for 24 mm precipitation event, and Figure 23 for 50 mm precipitation event). Areas characterized by high percentage of green cover presented higher retention value. The lower retention benefits (areas shown in purple), which resulted in more precipitation runoff, were observed in areas characterized by impervious surfaces, including constructed and sealed surfaces like sidewalks, roads, and parking lots, which prevent precipitation from infiltrating soils. The two large lakes (Pyhäjärvi and Näsijärvi) provided an important regulating service in buffering precipitation events and thereby decreased the volume of runoff throughout the drainage catchment.

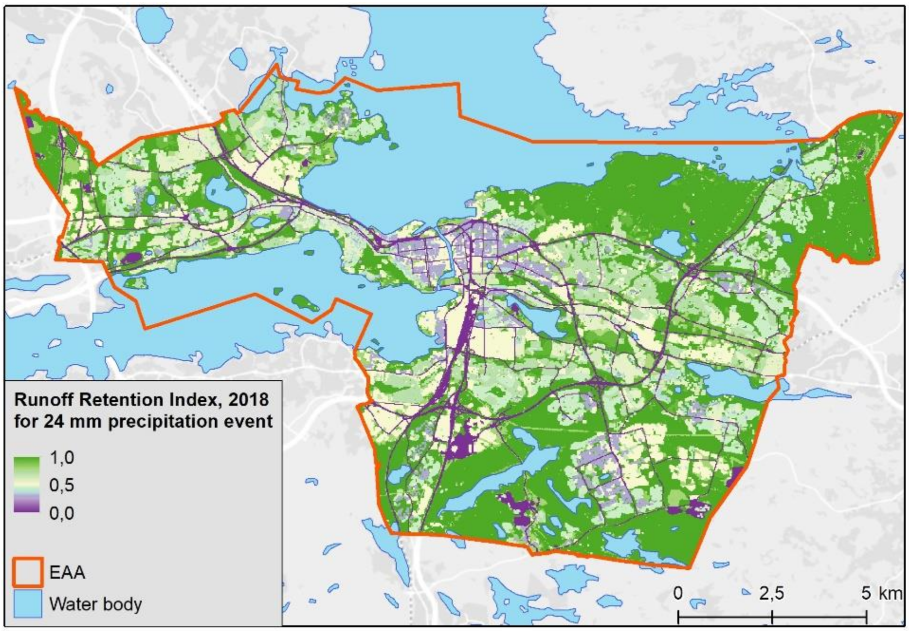

Figure 22. Runoff retention estimated using the ecosystem extent of 2018 based on a precipitation event of 24 mm. 1.0 represents maximum retention capacity and 0.0 no retention capacity. Background map: ESRI/MML, SYKE (Ranta250)

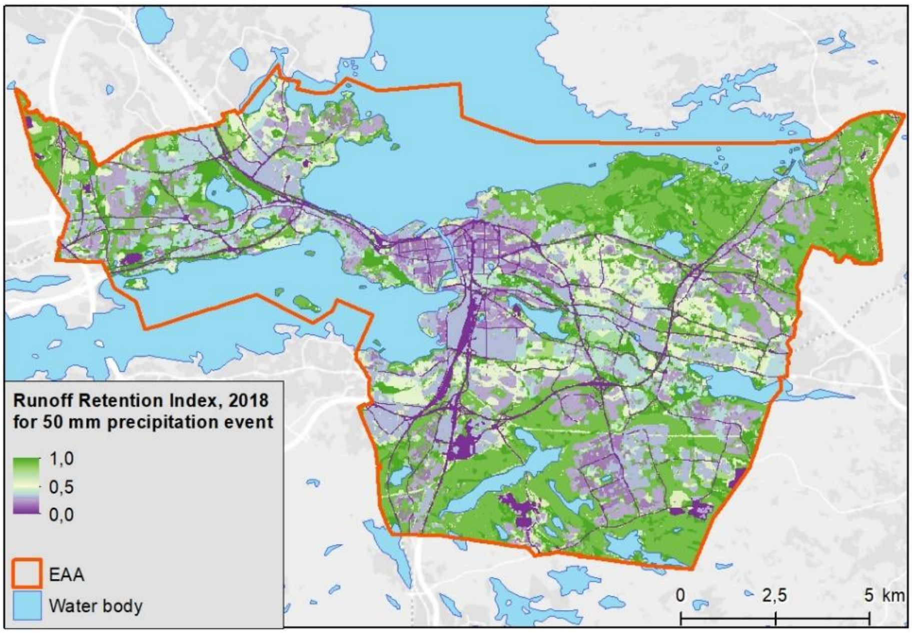

Figure 23. Runoff retention estimated using the ecosystem extent of 2018 based on a precipitation event of 50 mm. 1.0 represents maximum retention capacity and 0.0 no retention capacity. Background map: ESRI/MML, SYKE (Ranta250)

3.6.2.2 **From InVEST results to the physical term of the service for ecosystem accounting**

The amount of flow retention and volume surface runoff (m^3) were estimated by the InVEST model (Table 19). The total volume of runoff (Q_{vol}) generated increased by 250,3% (from 703197,7 to 2463477,8 m^3) with an increase of precipitation intensity from 24 mm h^{-1} to 50 mm h^{-1}. Between 2012 and 2018 there was a slightly decrease (-0,3%) in runoff retention volume, probably due to the ecosystem type conversions that happened during the same period.

Table 19. Flood risk mitigation model outputs for 2012 and 2018.

Year	Rain event depth (mm)	Runoff retention index (Average)	Runoff volume (m3)	Runoff retention volume (m3)
2012	24	0,71	703197,7	3349701,8
2012	50	0,83	2463477,8	5980062,4
2018	24	0,70	713418,9	3339480,6
2018	50	0,82	2493119,7	5950420,5

The runoff retention index and runoff retention volume derived from the InVEST model can be regarded as indicators reflecting the potential ecosystem services supply, regardless the demand or actual use of the services (UN 2021). In this pilot, we further overlayed the map of runoff retention index and building footprint map to get the area of buildings benefiting from runoff retention (where runoff retention index was larger than zero), which can be the metrics of actual ecosystem service flows of flood mitigation in physical terms (UN 2021). The area of buildings benefiting from the service were thus used as physical term of the service to compile the supply and use account.

3.6.2.3 **Valuation of the flood mitigation service**

In this pilot study, the damage avoided method was used to value the flood mitigation services: the damage cost that would have happened if the services disappeared were used as the value of the services (NCAVES and MAIA 2022; UN 2021). The flood depth-damage model presented by Huizinga et al. (2017) was applied to estimate the potential cost if the flood event happened with the flood height estimated by InVEST model. The maximum damage cost of residential, commercial, and industrial buildings from Huizinga et al. (2017) was adjusted to the context of Tampere with building cost index (Statistics Finland 2022a), building ages and material from the building footprint map, and the conversion factors from construction cost to the cost of building content, movable part, and inventory (Silander & Parjanne 2013).

The potential flood damage cost of each building was determined by the depth-damages curves in Huizinga et al. (2017), the adjusted maximum damage cost of different property (unit in EUR/m²), the area of each building, and the estimated flood height from the InVEST model. The differences between this potential cost and the potential cost of the highest flood from InVEST results are the estimated service value. The estimated ES value, potential cost, and the changes between 2012 and 2018 scenarios are shown in Table 20. The ES values were compiled into supply and use account in the Supplementary material 4.

Table 20. Potential damage cost and value of flood mitigation service in different scenarios

	Scenario	Industrial Sector	Commercial sector	Household	Total
Total potential damage cost if the flood event happens	2012 - 24 mm	4 641 634 €	6 217 895 €	20 863 936 €	31 723 465 €
	2018 -24 mm	4 667 086 €	6 427 976 €	22 577 191 €	33 672 253 €
	2018 -50 mm	14 610 927 €	19 222 709 €	71 176 513 €	105 010 149 €
Value of ecosystem services	2012 -24 mm	6 287 704 €	6 962 639 €	29 047 498 €	42 297 841 €
	2018 -24 mm	6 360 242 €	7 435 012 €	31 427 619 €	45 222 873 €
	2018 -50 mm	8 362 673 €	9 658 515 €	41 333 506 €	59 354 695 €
% change of total potential damage cost compared to 2012 - 24 mm	2018 - 24 mm	0,5%	3,4%	8,2%	6,1%
	2018-50mm	214,8%	209,2%	241,1%	231,0%
% change of ES value compared to 2012 - 24 mm	2018-24mm	1,2%	6,8%	8,2%	6,9%
	2018-50mm	33,0%	38,7%	42,3%	40,3%

3.6.2.4 Compiling supply and use account by linking flood migration service to extent account

The supply table was compiled by overlaying the location of the buildings that benefited from the runoff retention and the ecosystem type (Level 3). The physical term of the service (building area) and the service value were aggregated by different ecosystem types according to the location of the building. The use purpose of the buildings (residential, commercial, and industrial buildings) was the information provided in the building footprint map, which was used as a basis to allocate the service used by the commercial sector, industrial sector, and household. The results of the supply table can be seen Supplementary material 4.

3.6.3 Helsinki supply and use account for recreational service

3.6.3.1 **Explore the use of crowdsourced data to estimate the recreational service**

For Helsinki, recreational ecosystem service provided by urban green was selected for the pilot. During the first year we tested the use of crowdsourced spatial data to identify nature-based recreational hotspot within forested areas. We combined data from the popular social media platform Flickr, and from two citizen science applications (iNaturalist and eBird). Social media platforms are a promising source of data that has been widely used to inform about nature-based recreational activities. However, lack of validation data to estimate the correlation between the actual visitation of green areas and the visitation proxy estimated from the social media platforms limited the use of these data for the scope of this project. To overcome this limitation, during the second year we used data from the sport application Strava and available eco-counter data from the City of Helsinki.

Pedestrian (walking/hiking/running) and cycling data were retrieved from the Strava Metro online service to assess recreational use of the green areas within Helsinki municipality for the year 2019. Activities tracked by the sport application are reported in hourly intervals per street segment and per direction of travel in the anonymized and de-identified data available via Strava Metro. Road and path segments are based on spatial data from OpenStreetMap Strava data only represents a subsample of the total population and rounds up the number of people and trips per segment to five-count buckets. Therefore, these data need to be properly calibrated (i.e., using data from counter stations or questionnaire surveys) before making assumptions about the total activity.

Eco-counter (with two-way pyroelectric sensor) data for six locations were acquired via private communication from the city of Helsinki. Activity from each eco-counter was extracted and the number of people registered by the counter to both weekly and monthly counts was aggregated. To calibrate the Strava data, we performed a linear regression of the daily data from the six eco-counter locations and the Strava activity counts for the same time period and over the same trail or street segments.

After exploring all the data mentioned above, without a validation with a recreational survey, none of these data can be directly used to estimate the recreational services at municipality level. Therefore, a top-down approach to approximate the recreational services of Helsinki was tested in the pilot, by combining the data of national recreational survey in national inventory of recreational use of nature (LVVI), the population of in Helsinki, and the relative importance of visiting based on the Strava data. The steps of combining each data set can be seen in Figure 24.

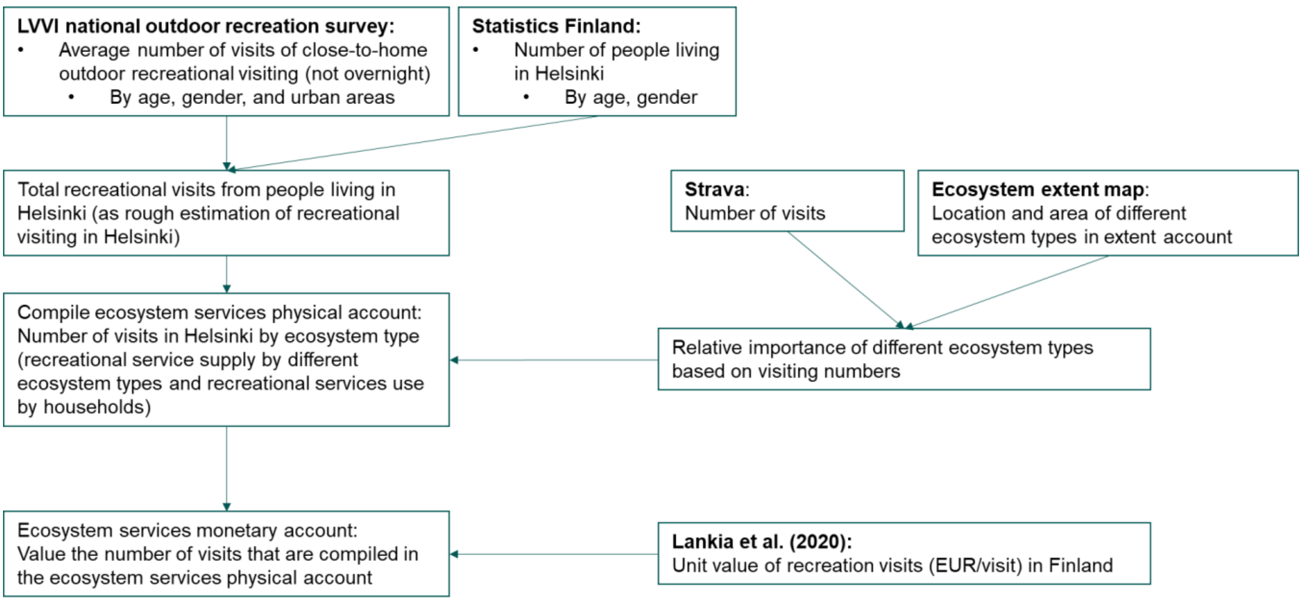

Figure 24. Summary of procedure to estimate recreational services in Helsinki and compiling the ecosystem supply and use account.

3.6.3.2 Relative importance of ecosystem types in terms of recreational visits based on Strava sports application data

In the absence of absolute visit count data, segment-level activity count data from Strava Metro were used to identify the relative importance of different ecosystem types. Activity counts for 2019 for each street segment were aggregated to Helsinki ecosystem types at level 4 (see Table 15) using a spatial overlay analysis. Trip counts in the Strava data were interpreted as recreational visits. The visit data were aggregated to the ecosystem types in two different ways: by calculating the average visit count and the accumulated visit count, for each ecosystem type. The relative importance of visiting by ecosystem types was also calculated in two ways: by directly transferring the average and accumulated visit counts to percentage, and, by following Kopperoinen et al. (2022), dividing both numbers by the average segment length per ecosystem type before transferring the values to percentages. Four types of relative importance of visiting can be seen in Figure 25. The figure shows that using different ways to calculate the relative importance leads to the results quite differently. For example, with average visit counts divided by segment length per ecosystem type, bathing beaches is extremely important ecosystem type for recreational visits. While using average visit count, the relative importance is relative equal for various types of urban green and forest.

There is a need for further exploration on which types of relative importance can better capture the recreational services in different ecosystem types. In this pilot, we use average visit count by ecosystem type to demonstrate the ecosystem services supply account.

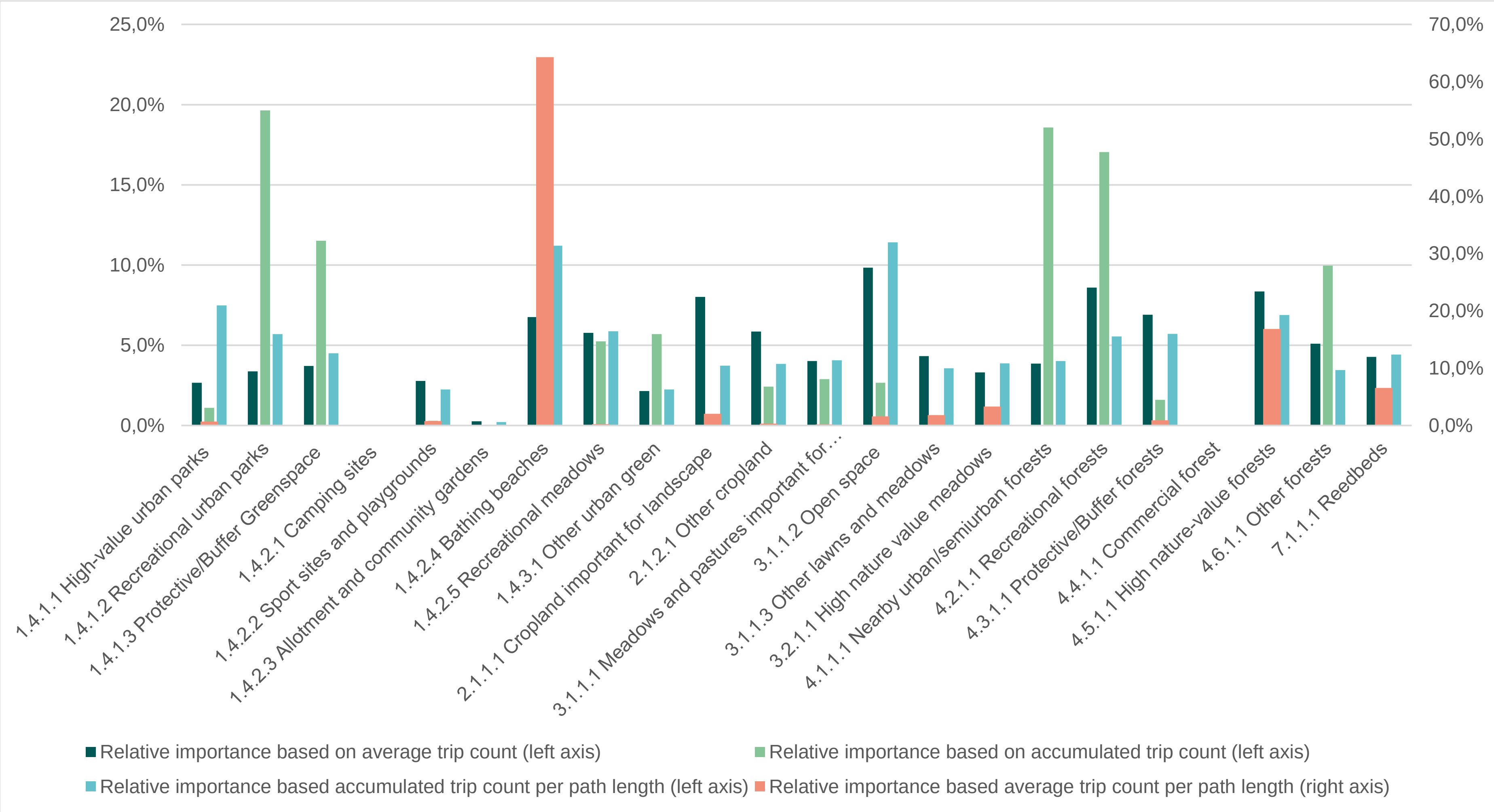

Figure 25. Relative importance of recreational visits by ecosystem types in Helsinki.

3.6.3.3 Estimation of ecosystem services from national to municipality level

LVVI data is based on natural recreation surveys conducted every 10 years to randomly selected Finns at the national level, and the latest one was conducted between 2019 and 2021. (Neuvonen et al. 2020). This pilot used the results from the last survey. One of the LVVI datasets provides the average number of one-day visits to close-to-home nurture in different gender groups, age groups, groups of regions, and a group of different municipality types based on population density (one classification is urban municipality) (see Table 21). For each group, it also provides a participation rate that excluded the population that did not do such visits in the past 12 months from the survey. With these average number of visits by groups and participation rate, we can approximately estimate the number of such recreational visits of Helsinki based on the population in Helsinki with four different values.

Table 21. Population of Helsinki (Statistics Finland 2022b), average number of visits to close-home nature in different groups and their participation rate (LVVI 2021)

Population of Helsinki municipality in 2019	Total	Male	Female	Average number of visits in age (% of participation)
Age				
0-14	93 557	47 818	45 739	-
15-24	70 646	32 985	37 661	156(97%)
25-44	224 703	111 956	112 747	165 (97%)
45-64	152 311	73,519	78 792	185 (96%)
65-74	64 429	27 434	36 995	226 (93%)
75-80	23 733	9 330	14 403	208 (90%)
81-	24 456	7 660	16 796	-
Between15-80	535 822	255 224	280 598	183 (96%)
Total	653 835	310 702	343, 133	-
Average number of visits in gender (% of participation)	-	173 (96%)	192 (95%)	
Average number of visits in urban municipality (% of participation)	178 (96%)	-	-	
Average number of visits in Helsinki-Uusimaa (% of participation)	180 (96%)	-	-	

Table 22 shows the lower bound and higher bound of the estimation of the recreational visits based on four types of averages. If the total population living in Helsinki was considered, the number of visits would range between 111-114 million. Table 22 also shows the number of visits for the population of age between 15-80 as this is also the range used in the LVVI survey. It needs to be noticed that such an approximation will overestimate the number of visits from people who live in Helsinki and underestimate the number of visits from visitors outside Helsinki. The lower bound of total visits was further used to compile the supply and use account.

Table 22. Number of close-to-home nature visits from Helsinki population.

All close-to-home visit (1000 visits)			
Total visit		**Visit between age 15-80**	
Lower bound	Higher bound	Lower bound	Higher bound
111 461	114 319	91 343	92 580
Based on the average visit from urban municipality	Based on the average visits in gender	Based on the average visit from urban municipality	Based on the average visits in Helsinki-Uusimaa region

3.6.3.4 **Valuation of recreational service and compiling the supply and use accounts**

Since the survey was not made in this Helsinki pilot, the original estimation of local recreational value is not possible. Therefore, by following Kopperoinen et al. (2022), the unit value from the existing Finnish recreational studies (Lankia et al. 2020) was used to estimate the value of the services and compile the supply and use account. In Lankia et al. (2020), the unit cost for recreational services is 1,9 EUR in terms of travel cost per visit, and 5,8 EUR in terms of consumer surplus per visit. Both numbers were multiplied with the estimated lower bound of total number of visits. The number of visits and their values of it were allocated to different ecosystem types according to the relative importance of ecosystem types. The supply and use accounts according to this allocation can be seen in Supplementary material 5.

3.7 **Discussion: lessons learnt from the pilots**

3.7.1 Compiling urban ecosystem extent accounts

Extent accounts require harmonized, validated, and comparable time-series data covering all ecosystem types for the whole extent of the EAA. Furthermore, the ecosystem assets represented in these accounts should represent ecosystems, they should be mappable, they should be geographically and conceptually exhaustive across ecological realms and they should be conceptually and geographically mutually exclusive (UN 2021). We were not able to identify spatial data from the piloting municipalities that would have fulfilled all the requirements. Therefore, the use of national-level data for municipal/urban extent accounts is unavoidable, and municipal data can have a more complementary - yet still very important – role in compilation of the accounts.

Challenges in data availability was identified as one of the risks for project implementation in the project proposal. After the data identification step, we can conclude that lack of "accounting-ready" data is a considerable challenge for urban ecosystem accounting in Finland at the moment. We would like to stress that the problem is not lack of spatial data as such – all pilot municipalities had good selection of spatial datasets available. Rather, it is the lack of data suitable and appropriate for ecosystem accounting at the scale needed for urban analysis. Municipalities in general, with the exception of larger cities, have limited resources to start collecting new data, and have to rely on existing data. In the following, we will briefly summarize the main challenges related to data.

Full compliance with SEEA EA standard and EU Ecosystem typology could not be achieved for any of the pilot extent accounts. But on the other hand, one could argue up to what extent the municipal accounts should be compliant with the SEEA EA standard, if their intended use is mostly at municipal decision making? After all, there is no standard for municipal EA, and certain degree of experimentation is needed to move forward, to see what works and what doesn't.

Despite all the shortcomings encountered, the pilots were, however, very useful in pointing out data gaps in municipal EA. To fill these data gaps, there are municipalities can either improve and develop their own existing data sets – such as the maintenance classes on urban green – towards being more "accounting-ready", especially in the sense of data management by keeping the old records as a time series. Municipalities can also decide to collect new data through airborne / droneborne remote sensing backed up by field work. Data collection with remote sensing requires carefully stated user requirements, planning, specific technical expertise and equipment, which is why it usually always is outsourced. Data collection campaigns are typically costly to set up but since the largest municipalities – like Helsinki and Tampere – are already doing regular data collection through LiDAR and aerial photography, it would be cost-efficient to include the data needs of municipal ecosystem accounting when next data collection campaigns are planned.

3.7.1.1 **Feasibility of applying maintenance classes as ecosystem assets**

One of the aims in our project proposal, in the task of piloting extent accounts, was to test how feasible it is to apply the urban green maintenance classes as proxies for ecosystem assets to populate these accounts. Like already mentioned in chapter 3.4.1, these data were available for all three municipalities, but in the end, we ended up testing them for Helsinki and Pirkkala extents.

The strength of these datasets is that they are collected and maintained by the municipalities themselves, so potentially they can have very detailed information on the distribution of various types of urban green and its characteristics. This can also strengthen the ownership of developing municipal accounts. In our Helsinki and Pirkkala pilots, we found out that various types of urban greenspace and many of the nearby urban, recreational and protective/buffer forests patches were missing from other national-level datasets used in the study. From this point of view, the maintenance classes can be useful when the total amount of urban green (including forests) in a municipality is the objective, or if the collected ecosystem extent information will be used in a higher aggregation level.

On the other hand, the maintenance class data fell short in many of the requirements for EA:

- The idea of using maintenance classes as proxies for ecosystem assets is problematic. This is because the maintenance classes are defined based on their land use or land management, instead of ecological or ecosystem, characteristics. Examples of these are classes *2.1.1.1 Cropland important for landscape* (with no information on crop types grown) and *4.1.1.1 Nearby urban/semiurban forests* (forests should be classified based on their tree species composition and other ecological features). In fact, many of the maintenance classes having strong land use component could fit better for land accounting rather than EA (UN 2022).
- Some of the maintenance classes are vague in their definition, like *3.1.1.2 Open space*. In Helsinki, for example, this class included very diverse ecosystem types such as water meadows, protective / buffer green areas, ruderal vegetation strips next to railroads, and even urban parks with tree cover.
- Due to the first two problems, cross walking the maintenance classes to EU ecosystem types is not straightforward. It worked best for urban greenspace subtypes (levels 3 or 4 in our typology). Croplands, grasslands and forests could only be cross walked to a higher level.
- No historical records of the maintenance classes were available; accounting for additions and reductions in their extent was not possible.
- The maintenance classes only cover a certain subset of urban green assets in a municipality. The limitations differ between municipalities, but typically only assets owned by the municipality are included, and assets which are within the urban area development plan area.

Some of these shortcomings are in conflict with the SEEA EA standard (UN 2021) and can potentially cause conflicts with other ETs in the extent account and lead to a potential risk of double counting.

3.7.1.2 **Feasibility of compiling accounts from different datasets**

In Ecosystem accounting, combining data from disparate sources is in many cases unavoidable (UN 2021). The reality is that there is a great wealth of spatial data, but it is scattered, incomplete, very often not fit for accounting purpose and collected in different years. The combination is possible, but tedious as it requires often considerable amount of data pre-processing and harmonization. Known limitations of the combination approach are that different datasets can have different characteristics in their data models (raster or vector), thematic detail, spatial accuracy, and temporal consistency. As the data is not standardized and each dataset is collected for different purposes, there is no way around this.

An attempt was made to automatize the pre-processing and harmonization steps by using geoprocessing scripts in R and QGIS. To some extent this was successful, but some manual processing steps were still unavoidable. This was because we noticed that the original data had geometrical, topological and attribute errors that had to be manually fixed. The more the compilation of accounts require manual – and often subjective – decisions to be made, the more difficult it is to replicate the results.

When datasets are combined using geoprocessing tools, care must be taken to avoid overlapping ecosystem assets which would lead to double-counting. Technically it is a straight-forward task, but the compiler of the accounts has to make very important decisions: what is the layering order (e.g., which datasets are considered primary and which secondary) and how to deal with resulting polygon geometries of the ecosystem assets after compilation. After a geoprocessing operation, where two polygon datasets are compared and overlapping portions erased, the polygon geometry of the ecosystem asset is changed from its original delineation.

As an example, when forest polygons from different data sources were merged and harmonized in the case of Pirkkala, some of the derived forest polygons after these geoprocessing steps do not represent homogeneous "forest stands" in their ecological or forestry characteristics anymore. Moreover, the geoprocessing often results in geometrical artifacts, also known as sliver polygons, which are artifacts of geometrical errors in the source data, rather than real forest assets. This is not an issue if the aim is to aggregate the extent of all assets of the same ET (to know, for example, how much forests or urban greenspace there is in a municipality), but it becomes an issue if the aim is to account on individual assets for their condition or supplied ecosystem services.

All in all, communicating the uncertainties in the source data and how they are propagated to the extent account is very important for the usability and credibility of urban EA. This is a big challenge when extent account is compiled from various sources, as quantifying the uncertainties becomes also more difficult. In this study, we were not able quantify uncertainties of the extent accounts of Pirkkala and Helsinki since this information was not available for the source data.

3.7.1.3 **Feasibility of compiling accounts from high resolution CLC**

At the moment, we recommend the use of Finnish national high-resolution CLC accounting layers for compiling extent accounts in Finland, if a full extent account covering all ecosystem types and the ability of tracking ecosystem conversions is needed. According to our assessment, it is the only national spatial data for extent which can be considered "accounting-ready". It seems likely that the first Finnish national extent accounts will be based on this data. We have shown in this study that when the use case of urban EA is well planned, CLC can be applied in municipal EA as well, despite its rather coarse spatial resolution and lesser thematic detail for urban ETs.

It is important that decision makers and other users of municipal EA understand the limitations of the data. For this reason, any kind of estimations of the accuracy of the data is of high value. Using our approach, the overall accuracy of the 2018 national high-resolution CLC was assessed to be 84 % (Härmä et al. 2019), which is sufficient for EA purposes. We further reduced uncertainties by aggregating similar classes and thus reduced the number of ecosystem types.

3.7.2 Limitations in estimating ecosystem service supply and use

3.7.2.1 Challenges in applying map-based survey to collect data for ecosystem services

Ideally, the map-based survey is a good tool to collect the data for estimating the ecosystem services as it can identify the location of using the ecosystem service to establish the linkage to the ecosystem extent account. However, based on the survey experiences, a couple of things should be carefully considered. Firstly, comparing the experiences from the two surveys, which survey platform is used is a critical issue. Selecting a survey platform that is user-friendly enough influences the response rate and the accuracy of the collected data. Also, the accuracy of marking the location of the ecosystem service use is influenced by how close the respondent zooms in on the map when marking the point. Therefore, a survey platform that can include the zoom-in level when the points are marked will be a better option. Secondly, the marking issue is also related to linking the service data to the extent account. For example, in the case of this pilot, when the extent account is not compiled to cover all the land cover, respondents may mark the places outside the accounted extent types, either because of the accuracy issue mentioned above, or a mismatch of defining of the green spaces between the respondents or researchers. In this pilot, we temporarily classified those service supplies into other ecosystem types. In practice, two possible solutions could be used to solve this problem. First, choosing the platform that can limit the respondents not to mark at places outside the accounted ecosystem types. Alternatively, compiling the extent account that covers all the land cover, and considering an extent of error in linking the service to the wrong extent would happen.

3.7.2.2 Challenges in acquiring data on ecosystem service use

Exact data on visits to urban ecosystems is often lacking or very sparsely sampled and not representative of various ecosystem types. In this pilot, count data from eco-counter sensors were available for six locations in Helsinki. Counter data also has its own challenges related to capturing the exact number of passers-by, for discussion see Kajala (2007).

In the absence of exact visit numbers across ecosystem types except for the sparsely located counters, crowdsourced data from mobile applications can be useful when estimating the use of urban ecosystems (Heikinheimo et al. 2020). Crowdsourced data are biased towards specific user groups which should be considered when interpreting the results. Furthermore, mobile applications may be subject to changes e.g. in data format, accuracy, popularity of the platform and access to data all of which pose challenges for longitudinal use of the data (Toivonen et al. 2019).

In the case of Strava Metro data, the user base represents physically active people who have chosen to track and share their cycling or pedestrian activities. In the pilot study data, ~85 % of the users were male and over 50 % of the users were aged between 35-54 years according to Strava Metro. The aggregation of Strava data to five-count buckets also limits it's use, especially in areas with very low numbers of users (Raturi et al. 2021). Regardless of the known limitations, Strava data may be helpful in identifying the most popular sites and relative importance of various ecosystem types for recreation as exemplified in the pilot.

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4 Developing pilot accounts for packaging materials (WP4)

Johansson Annika[1], Jylhä Henna[1], Salminen Jani[1], Sorvari Jaana[1]

[1] Finnish Environment Institute (Syke)

4.1 Introduction to the project

Packaging of various goods makes a significant contribution to the overall use of materials in the European Union (EU) and globally. In 2017, the amount of packaging waste per capita was 173 kg and the amount of is only expected to increase in the future. (EU 2020.) Hence, packaging and packaging waste are highly relevant for the environmental policy of the EU, and e.g. waste policy therein, as it strives towards resource-efficient and competitive low-carbon Circular Economy (CE).

The goal for the EU is that all packaging waste is either recyclable or reusable in an economically viable way by 2030. Directive on packaging and packaging waste from 1994 (94/62/EC) sets recovery and recycling targets for packaging materials and obligations for the Member States on databases and reporting of packaging and packaging waste. Directive (EU) 2018/852, amending the directive 94/62/EC, further raises the recycling targets. Similarly, the Member States' reporting obligations are becoming more demanding. Packages are also of high interest in the context of littering, waste accumulation in aquatic environment and policy tools, such as Directive (EU) 2019/904 on the reduction of the impact of certain plastic products on the environment known as SUP (single-use plastics) directive intended for restrict this adverse development. The European Commission's recent Action Plan for Circular Economy (2020) focuses both in increasing the recycling rate of materials and in reducing packaging and packaging waste.

The Work Package 4 (WP4) contributes directly to monitoring the transition to a Circular Economy (CE) in the EU. Material flow analyses were performed for a set of 5 different packaging materials, paper and cardboard, plastics, metal, glass and wood packaging and their combinations (where applicable). In addition, data gaps and inaccuracies were observed and highlighted to recognize the areas of future development needs. The analyses were done in a highly disaggregated manner which makes it possible to observe the contribution of each specific industry to the packaging material flow. In addition, the estimates are consistent with existing national material flow accounts.

Objectives

The stated specific objectives and tasks in WP4 were:

- Develop methodology and to compile accounts for packaging materials brought to the market – including imports and foreign trade – and for the generation of packaging waste.

- To develop methodology that can be applied to compile detailed supply and use tables (i.e. accounts) to various packaging materials and their combinations.
- To compile supply and use tables (i.e. accounts) for a set of packaging materials (including packaging waste) and their combinations by applying the methodology developed.
- Compilation of material-specific packaging accounts (task 4.1).
- Compilation of material-specific packaging waste accounts (task 4.2).

4.2 **Background**

4.2.1 Definition of packaging

Packaging is defined as being material used for containment, protection, handling, delivery and presentation of intermediary and consumer products. For example, a product may be in sales packaging, sales package in group packaging and these together in transport packaging. Packaging also applies to 'non-returnable' items used for the same purposes and secondary packaging used for example group sales units to replenish shelves at the point of sale. By definition, packaging materials are subject to sales and purchasing activities (European Parliament and Council Directive 94/62/EC.) Packaging can be of mono- or multimaterial.

Packaging provides information and promotes the sale of the product. All parts of the package that reinforce or are attached to it, such as labels, are considered packages (Finnish national regulation on packaging and packaging waste 518/2014). The quantities of different materials in the package and the possibility of separating them determines whether the materials are taken into account or counted as part of the main material.

Some products such as sheets of paper are not considered packaging at the time of their manufacture but become packaging only at their use, for example, when they are used to wrap sold flowers.

Packaging is divided into business and consumer packaging depending on the end user. Business packaging ends up into companies whereas consumer packaging ends up to consumers or households.

4.2.2 Legislation

Packaging and packaging waste are regulated both at EU and national level. EU Regulations are binding acts that must be applied in their entirety throughout the Member States as such. EU directives, on the other hand, set targets for all EU countries, but it is up to each Member State to decide on the national legislation to achieve the objectives. The EU and Finnish national legislation on packaging and packaging waste includes the following;

- EU Directive on Packaging and Packaging Waste 94/62/EC

- EU Directive on Waste and repealing certain Directives 2008/98/EC
- EU Directive on the reduction of the impact of certain plastic products on the environment (SUP Directive) (EU) 2019/904
- EU Directive on reducing the consumption of lightweight plastic carrier bags (EU) 2015/720
- Council Decision (EU, Euratom) on the system of own resources of the European Union 2020/2053
- EU Regulation on materials and articles intended to come into contact with food 1935/2004
- Finnish Waste Act 646/2011 and its amendments
- Finnish Government Decree on Waste 978/2021
- Finnish Government Decree on a Return System for Beverage Containers 526/2013
- Finnish Government Decree on Packaging and Packaging waste 1029/2021

In addition to legislation, standards have a significant impact on the design of packaging.

EU Directive on Packaging and Packaging Waste 94/62/EC

The goal for the EU is that all packaging waste is either recyclable or reusable in an economically viable way by 2030. Directive on packaging and packaging waste from 1994 (94/62/EC) set for the Member States recovery and recycling targets and obligations on databases and reporting. Directive (EU) 2018/852, amending the directive 94/62/EC, further raised the recycling targets (Table 23). The recycled amount is calculated from the measured weight of the packaging waste entering a recycling operation. This means that the reject from sorting and other preliminary operations are not included in the amounts reported as being recycled. The measures used to estimate the rejected amount are reported to the Commission in the quality check reports accompanying the data on waste recycling. Average loss rates are only used in situations without available data. This applies, for example, to exports and shipments of waste. The material losses during recycling packaging waste into new products by physical or chemical transformation processes does not affect the amount of waste reported as being recycled.

According to the Directive 2018/852 the most efficient way to improve resource efficiency is to increase the share of reusable packaging placed on the market. The ways the Member States could encourage this is by using a deposit compensation scheme or compensation in producer responsibility payments.

The Member State exporting waste to another EU state for recycling may account the recycled amount in their country statistics. If packaging waste is exported outside the EU for recycling, it can only be included in the statistics if there is documented evidence of the recycling of the waste. The assurance can be received by cooperation with the competent authority, independent third-party verification bodies or producer responsibility organizations of destination.

Extended producer responsibility must apply to packaging in all Member States by the end of 2024.

To support the growth of packaging reuse and recyclability Annex II to Directive 94/62 / EC sets out requirements for the composition, reusability, recyclability and recoverability of packaging.

Table 23. Recycling targets for different packaging materials according to EU Directive 2018/852 (% in specific materials packaging waste)

Material	Target 2025	Target 2030
paper and cardboard	75 %	85 %
plastic	50 %	55 %
wood	25 %	30 %
ferrous metals	70 %	80 %
aluminium	50 %	60 %
glass	70 %	75 %

EU Directive on Waste 2008/98/EC

The Directive 2008/98/EC sets down the waste hierarchy to be prioritized in packaging waste prevention and waste management policy and legislation starting from prevention, preparing for re-use, recycling, other recovery and ending up in disposal (article 4). The re-use, prevention and recycling of packaging waste is promoted through extended producer responsibility. This is based on the producer pays principle, where the producers of products have a responsibility for the product disposal. Member States need to ensure that measures such as acceptance of returned products and waste left after product use and subsequent waste management and financial responsibility for such activities. (Article 8.)

Article 3 of the Directive gives definitions to the words waste, collection, prevention, re-use, recovery, recycling etc.

EU Directive on the reduction of the impact of certain plastic products on the environment (SUP Directive) 2019/904

SUP Directive relates to single-used plastic products, that are by their design not easily recyclable or re-usable. It is set for response to The EU Plastics Strategy (2018) call to reduce the negative impacts caused by the generation and the leakage of plastic waste into the environment. Estimation of 80-85% of marine litter is plastic from which 50% is single used. The Directive promotes the production of recyclable plastic products and supports the target set on all plastic packaging placed on the market being re-usable or recyclable by 2030.

The Directive either prohibits or seeks to reduce the placing on the market of certain disposable plastics (Article 4 & 5). The products falling under the prohibition includes single-used plastic products made of expanded polystyrene (PS) like beverage containers and cups, including their caps and lids and food containers with food for immediate consumption (Directive Part B). Restrictions on the other hand apply to products such as beverage cups, with their covers and lids and fast-food containers with food intended for immediate consumption. Containers with dried food, food that requires preparation, contains more than one serving or includes more than one unit are not covered by the Regulation (Directive Part A). The monitoring is done by measure the quantities of products and not their weights.

The member states are required to put in place an extended producer responsibility scheme for products such as food containers and their covers with food intended for immediate consumption, beverage containers (up to 3 litres) and cups including their caps and lids, and lightweight plastic carrier bags. Member states shall ensure that the caps and lids of plastic and composite beverage containers (up to 3 litres) remain attached to the containers in their use stage from 3.7.2024 (Article 6 (1), Directive Part C).

The recycling target for single-used beverage bottles (up to 3 litres) including their caps and lids is 77% by 2025 and 90% by 2029 of products placed on the market by weight (Article 9). By 2025, 25% of bottles must be recycled plastic, and the target will rise to 30% by 2030.The progress under the Directive shall be reported to the Commission annually.

Further guideline is needed for defining the products that fall under the Directive. For example, there is uncertainty as to whether or not packaging placed on the market empty and not intended to be filled at the point of sale is covered by the regulation or not. Further guidance is also needed in deciding whether a beverage packaging is a cup or a beverage container (up to 3 litres) and thus what obligations apply to it.

EU Directive on reducing the consumption of lightweight plastic carrier bags (EU) 2015/720

The regulation aims to reduce the use of lightweight plastic carrier bags with a wall thickness below 50 microns, as they are rarely reused and prone to littering. The measures taken by the Member States can target the amount of lightweight plastic bags consumed by a person a year, target being less than 90 bags per person a year by 2019 and 40 bags per person a year by 2025, or to prevent the free distribution of lightweight plastic bags at points of sale of goods and products by 2018 (article 2).

Member States are required to report annually to the Commission the consumption of lightweight plastic carrier bags on packaging obligations. The Directive is an amendment to the Packaging and Packaging Waste Directive. The deadline for reporting the consumption for the reference year 2018 was June 2020. This was used to assess the effectiveness of the measures put in place (European Union 2022).

Council Decision (EU, Euratom) on the system of own resources of the European Union 2020/2053

According to the decision, a new fund category was created based on the amount of non-recycled plastic packaging waste. The general idea is that the more non-recycled waste is generated, the more the Member State is obliged to contribute to the system. The decision aims to reduce the consumption of single-use plastics, support recycling and boost the circular economy.

The amount of non-recycled plastic packaging waste is determined on the basis of the calculation and reporting requirements of the EU Directive on packaging and packaging waste (EU) 2018/852. The rate is 0,80 euros per kilogram of plastic packaging waste generated and not recycled by the Member State.

EU Regulation on materials and articles intended to come into contact with food 1935/2004

This regulation supports the safe use of recycled materials. Material that is in contact directly or indirectly with food must prevent the transfer of substances in quantities large enough to endanger human health or reduce the quality of the product.

Finnish Waste Act 646/2011

Producer responsibility applies to a producer or importer of packaging with a turnover of more than one million euros (Article 48). The responsibility lies with companies that pack their products in Finland, import packaged products or sell their products in Finland online. A company is also responsible for its packaging when the packaging or logistics of its products are outsourced to another company. The administrator of an online store can handle the producer responsibility obligations on behalf of the producers selling on the platform. Producers outside Finland must fulfil their obligations either through an authorized representative or by joining a producer organization.

According to Article 68 producers can join a deposit- based return system on beverage packages (2021/714). The operator of the return system shall maintain a publicly available, up-to-date list of its owners and members which includes their names, businesses, corporate identity's, as well as data on the products he has placed on the market and the fees paid to the refund system on a unit or mass basis. (Article 69.)

Waste collected separately for re-use or recycling shall not be incinerated or landfilled (Article 15a).

Finnish Government Decree on Waste 978/2021

The municipality has an obligation, in co-operation with the packaging producer association, to provide a separate collection of glass, metal, plastic, paper and cardboard packaging waste generated in property with five or more residential apartments.

The requirement for the separate collection of non-residential waste applies to circumstances where these are more than 2 kilograms of glass packaging, metal packaging or small-scale metal waste generated weekly.

Finnish Government Decree on a Return System for Beverage Containers 526/2013

Beverage packaging return targets have been set according to the amount of beverage packaging placed on the market by the return operator's members and the quantities returned. The target for reusable and single-used beverage packaging are the same, from the mass of beverage packaging placed on the market at least 90% needs to be returned. The operator needs to reach these targets after the third full calendar year of operation. (Article 3.)

The deposit on the beverage packaging ranges from 0,10-0,40 euros (metal packaging 0,15 €, 0,20 € from 0,35-0,99 litra plastic packaging, 0,40 € plastic packaging of 1 litra or more, 0,10 € all other beverage packaging) (Article 2).

The operator is obliged to provide the Pirkanmaa Centre for Economic Development, Transport and the Environment annual data on the number of beverage packaging placed on the Finnish market, returned to the operator, send to be recycled or reused and the name and location of the receiving establishment by type of material and packaging in pieces and tonnes. The operator also needs to provide information on the method used for evaluating or calculating the information reported. (Article 7.)

Manufacturer or importer who is not a member of beverage packing return scheme is obliged to pay a beverage packaging tax of 0.51 euros per liter of packaging of certain alcoholic and soft drinks according to the Finnish national law on excise duty on certain beverage packaging (1037/2004). Manufacturers releasing to the market 70,000 liters or less a year are exempt from the tax (Vero 2022).

Finnish Government Decree on Packaging and Packaging Waste 1029/2021

National regulation on packaging and packaging waste 1029/2021 entered into force at the end of November 2021 amending the previous regulation from 2014 (518/2014). Regulation applies to producers who are not members of a deposit-based beverage packaging return operator and have a turnover of more than one million euros.

The new regulation (1029/2021) requires more detailed reporting than the old one (518/2014). The producer or producer organization on behalf of its members are obliged to provide to the responsible authority (Pirkanmaa Centre for Economic Development, Transport and the Environment) annual data on the mass of sales and other packaging placed on the Finnish market. Previous reporting obligations did not require the separation of packaging into sales and other types.

The mass-based reporting for separately collected packaging waste did not change between the regulations. The new obligation for the packaging waste collected on behalf of the producer, is to report the weight being recycled, recovered or disposed, broken down by material and the name and location of the treatment facility. Unlike before, the reject from sorting and other preliminary operations is not included in the calculated recycled amount. The repaired wooden packaging is calculated as recycled wood and metals recovered for recycling from waste incineration slag as recycled metal. Each material in a multimaterial packaging shall be counted and declared for, if the proportion of the material exceeds 5% of the total weight of the package. If the proportion is below 5%, the total weight of the package is calculated and reported for the main material of the package. Article 8 sets the material specific packaging recycling targets for 2025 and 2030, which are calculated on the basis of the mass of recycled packaging waste from the total amount of packaging of that material placed on the market by those under producer responsibility (Table 24). The mass of recycled packaging includes material recycled either in Finland or abroad. The exported waste is only recorded as recycled when recycling can be demonstrated in accordance with the National Waste Law's (246/2011) article 117 b.

The national recycling targets are in line with the targets set by EU Directive on packaging and packaging waste (EU) 2018/852, except for aluminium, which has a higher recycling target in the national regulation. The EU regulation (2018/852) compares the amount of recycled packaging waste with the amount of packaging waste generated, while the national regulation (1029/2021) compares the amount placed on the market by producers under producer responsibility. According to the Commission Decision (2005/270/EC) packaging waste generated can be thought as equal to the amount of packing placed on the market.

When assessing the achievement of the targets set for 2025, the level of targets may be adjusted by up to five percent by deducting reusable sales packaging placed on the market for the first time during the previous three years from the amount of all packaging placed on the market.

Table 24. ***Recycling targets for different packaging materials according to National Regulation 1029/2021****. The recycling target based on the mass of a specific packaging material placed on the market by those responsible for producer responsibility, which equals packaging waste generated. EU targets from Regulation (2018/852) are in line except for aluminum, which has the EU target in brackets.*

Material	Target 2025	Target 2030
paper and cardboard	75 %	85 %
plastic	50 %	55 %
wood	25 %	30 %
ferrous metals	70 %	80 %
aluminum	70 % (EU 50 %)	80 % (EU 60 %)
glass	70 %	75 %

The new regulation also brough changes to the reporting of reusable packaging. Previously only the annual weight of reused packaging was reported. The new requirement is to report separately the quantities of reusable sales and other packaging and to distinguish the packaging released on the market for the first time from the ones recycled more than once.

The producer organization responsible for reporting also needs to provide information on the method used for evaluating or calculating the data provided. Previously what was required was the reporting of the mass of reused, recycled and otherwise utilized and disposed packaging waste.

The producer responsibility payments favour reusable packaging or packaging which contains secondary material over packaging which is either hard or unrecyclable (article 12).

Summary

The summary of recycling targets for different packaging materials are shown in Table 25. EU and national targets are in line except for aluminium, where national targets are set higher to the EU's. There are separate recycling targets in plastics for lightweight carrier bags and for single used packaging.

Table 25. Recycling targets for different packaging materials according to EU and National Regulation

Material	Target 2025	Target 2029	Target 2030
paper and cardboard	75 %		85 %
plastic - single-used beverage bottles w/ caps and lids (up to 3 l) - lightweight plastic carrier bags	50 % - 77 % (25% made from recycled plastic) - 40 bags per person a year	 - 90 %	55 % - 30% made from recycled plastic
wood	25 %		30 %
ferrous metals	70 %		80 %
aluminum	70 % (EU 50 %)		80 % (EU 60 %)
glass	70 %		75 %

4.3 **Methodology**

4.3.1 Data collection

The data sources listed below were used in parallel to achieve the objectives of the project and to ensure the reliability of the data.

- Surveys for packaging manufacturers on material composition (mono- or multimaterial) and amount of packaging manufactured
- Finnish Packaging Recycling RINKI Ltd (a non-profit service company owned by Finnish industry and retail trade): Customer register including companies' industrial classification and turnover and data of packages released on the market
- Suomen Palautuspakkaus Ltd (Palpa) (producer responsibility organization, deposit-based beverage packages): Customer member list and data of packages released on the market
- Pirkanmaa Centre for Economic Development, Transport and the Environment (Pirkanmaa ELY Centre): Producer responsibility statistics
- The Finnish Packaging Association: Customer member list
- Suomen Kiertovoima KIVO ry (an umbrella organization for public waste management, treatment and disposal enterprises): Data bank on the material composition of mixed municipal solid waste (mixed MSW)
- Statistics Finland:
  - Input-Output statistics / Supply and use tables
  - Industrial output statistics
  - Regional business data and enterprises in the business register
  - Waste statistics
- Finnish Customs Database (Uljas): Amounts of imported and exported packaging

- Asiakastieto.fi (publicly available databases on companies' turnover and industry categories

4.3.2 Data analysis and use

To facilitate the collection and analysis of data, the following structure of the cradle-to-grave hierarchy concerning packaging, packaging waste and secondary materials was defined. The system includes the following steps (Figure 26).

- Manufacture of packages, imports and exports of packages
- Packages released on the market by industry
- Packages intermediate and final usage
- Generation of packaging waste
- Packaging waste collection and pre-treatment
- Packaging waste received and processed in secondary material production and reject thereof (not in the scope of this project)
- End-products: manufactured secondary materials supplied to the market (not in the scope of this project)

Figure 26. The different life cycle stages of packaging. 4.3.2.6. not in the scope of this project (light grey).

The types of materials and their combinations (multimaterial packages) analyzed in this project were paper & cardboard, plastics, metals (ferrous metals & aluminium), glass and wood.

4.3.2.1 **Manufacture of packages**

First, quantitative and monetary data on the amounts (in kg or pieces) and value of sales (in €) of packages produced were available in the industrial output statistics of Statistics Finland. Data were collected for paper and cardboard, plastic, wood and metal packages. Glass packages were not manufactured in Finland. Quantities in pieces were converted to masses using average package weights obtained from different data sources. The data from the Statistics Finland did not include exact data on the material composition of the packaging (e.g. multi- or monomaterial) or on the amount of packaging waste generated upon their manufacturing. Packaging waste from the manufacturing of packaging was considered pre-consumer waste and thus not included in the producer responsibility packaging waste statistics (1029/2021).

Second, a survey targeting packaging manufacturers, that is, paper and cardboard (NACE 1721), plastic (NACE 2222), metal (NACE 2591 and 2592), and wood (NACE 1624) package manufacturing companies. The packaging manufacturers were identified from the publicly available members list of the Finnish Packaging Association and supplemented with companies identified from a publicly available database (Yritystele.fi). The company's industry and turnover were obtained from the public data service (Suomen Asiakastieto Oy) and verified against Statistics Finland's data on regional entrepreneurial activities. The amount of imported and exported packaging was obtained from the Finnish customs database. The data did not include the packaging of products. In the survey, following data were collected: production quantities of packaging in tons and their material breakdown into mono- and multimaterial packaging, the plastic types contained in the packages, amount of packaging waste generated during manufacturing, number of packages subject to the SUP -Directive and the amount of recycled material used in the production of packaging.

For those manufacturers that did not respond to the survey, an upscaling of the data was done by the proportion of the missing turnover of that of the entire industry. Here, an assumption was made that manufacturing per turnover would be the same as in other packaging manufacturing companies. The data sources and type concerning packaging manufacturing are presented in Figure 27.

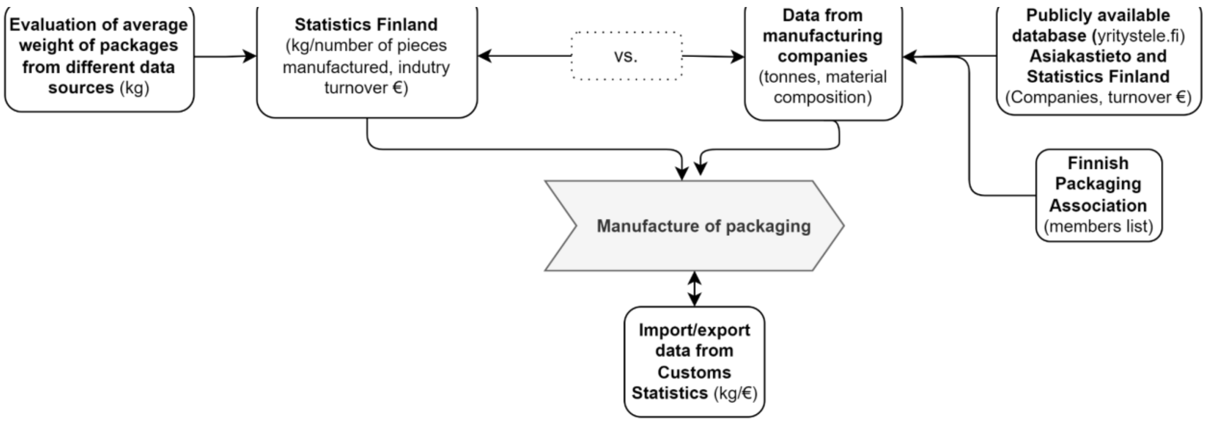

Figure 27. The data sources (in bold) and data type (in parentheses) concerning packaging manufacturing.

4.3.2.2 Packages released on the market

Packages are released on the market by companies based in Finland, companies abroad by online sales and by private imports. A substantial part of the packaging flow to the market is recorded in the producer responsibility statistics. The statistics exclude packaging placed on the market by companies with a turnover of less than one million euros, free-riders of the system, and packaging imported through private imports and online sales from abroad. An estimate of missing package volume is added to the statistics. Below we introduce new methods to produce an estimate on the packaging flows outside of producer responsibility register. The overall amount of packaging remaining outside the statistics was estimated to be approx. 16%. Previous estimate was slightly lower than this, 14% (YM 2021). The data sources and types concerning packages released on the market are presented in Figure 28.

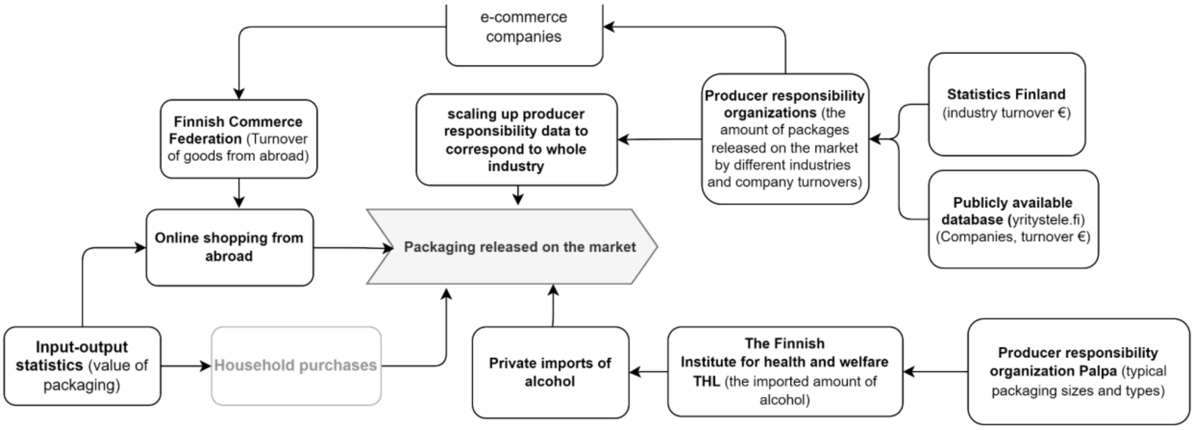

Figure 28. The data sources (in bold) and data types (in parenthesis) concerning packaging released on the market.

4.3.2.2.1 Producer responsibility and a method to compile industry-specific accounts

The majority of packaging placed on the Finnish market are recorded in the producer responsibility statistics compiled by the responsible authority (Pirkanmaa Centre for Economic Development, Transport and the Environment) and further reported to the Commission. The statistics are compiled on the basis of the quantities of packaging placed on the market reported by the companies belonging to the producer responsibility system. Also, an estimate of package flows outside of reported numbers are estimated and included to the statistics.

In addition to the packaging of products, companies report the packaging used to transport them, even if the transport is purchased from another packaging or logistics service company. Materials in multimaterial packaging are reported separately when the materials are manually removable. In case they are not removable, materials in multimaterial packaging are counted and declared for separately when the material exceeds 5% of the total weight of the package. If the proportion is below 5%, the total weight of the package is calculated and reported for the main material of the package. (Finnish national regulation on packaging and packaging waste 1029/2021).

Finnish Packaging Recycling RINKI Ltd is a non-profit service company owned by Finnish industry and retail trade. It is responsible for collecting the packaging data from companies and reporting it to the producer organizations and authorities as well as maintaining packaging waste collection infrastructure. The reporting practices to RINKI Ltd can vary. Franchise companies may report the packaging quantities of some or all of the individual franchisees. Individual franchisees can join the system themselves with their own business ID and report their own packaging quantities. Some may have a turnover of less than 1 million euros in which case they have no producer responsibility obligations. Also, some consolidated corporations do the reporting on behalf of their daughter companies.

Palpa Ltd takes care of approx. 97% of producer responsibility obligations regarding deposit- based plastics, metal and glass beverage packaging (PALPA 2022). Since 2019, it has been possible to join the deposit system not only for taxable products but also for tax-free products. Errors can occur in these statistics as the reporting is based on average weights of the packages. In order to minimize errors, the average weights of the packages are updated yearly by Palpa (Jokinen et al. 2015). A separate entity to Palpa, Ekopulloyhdistys Ry manages the responsibility obligations of reusable glass bottles. At the moment, there are also two other separate deposit-based systems operated by individual companies. The role of these systems are currently of minor relevance in terms of the total packaging volumes. Companies that are members of a deposit- based system are exempted from paying beverage packaging tax, which is an obligation when the quantity released on the market exceeds 70,000 liters.

Companies that are not members of producer responsibility organizations may do their packaging declarations directly to the responsible authority, which only applies to a few companies.

The packaging volume placed on the market by companies not included in the producer responsibility statistics has been previously estimated in Finland in the study conducted in 2015. This work was based on Fonecta enterprise database and The Environmental Register of Packaging (PYR, predecessor of RINKI) customer register. The number of companies which were not in the PYR register (both free-riders and companies with the turnover less than one million euros) in the industries which are packing the most was estimated and their packaging volume were calculated by using the packaging median in PYR register in different turnover classes. The total estimated packaging material volume was 110 117 tonnes. Shares of different package materials were not identified.

Packages on the market by industry – a new method

In this study, we developed a method to compile industry-specific accounts for different packaging materials. The aim was to account for the volume of packages released onto the market by companies with a turnover less than one million euros and the free-riders of the system. Hence, comprehensive accounts on the packages placed on the market would be generated.

The basis for the work were RINKI and Palpa customer registers containing information on the member companies, their standard industrial classification (NACE code) and turnover. The data were completed by using Asiakastieto.fi web portal and verified against Statistics Finland's microdata on regional entrepreneurial activities (NACE affiliation and turnovers). The companies for which turnover information was not available were removed from the sample. The companies were grouped according to their industry and aggregated to guarantee confidentiality (at least 8 companies per industry). Accounts were compilated for 164 individual-and aggregated industries. Individual industries (73) and aggregated industries (91 aggregated classes containing 340 industries), for which the accounts were compiled, are presented in Supplementary material 8. The acquired data on packaging was classified according to materials and business and consumer packages were separated.

The raw data provided by RINKI was upscaled by utilizing the Statistics Finland's data on industries' total turnovers and assuming that package-to-turnover ratio, that is, the ratio between the amount of packages released to the domestic market and the turnover is independent on the volume of turnover. In practice this means accounting for the enterprises not included in the RINKI customer register. The packaging volumes were upscaled before merging the industries to avoid error that would arise from merging industries that may have different packaging intensity (kg/€). Upscaling was not done for those industries, where packaging is occasional (as judged by the share of the sum of the reporting companies' turnover and number of the total turnover and number of companies within that industry), and for Palpa data, since almost 100% of all deposit beverage packages are included in the raw data. Eventually, RINKI and Palpa data were summed up. By comparing the summarized and upscaled numbers to the raw data provided by RINKI, we estimated the material-specific packaging flows released on the market by the free-riders and companies with turnover less than one million euros.

To estimate the coverage of complied accounts, we identified industries which had reported buying of package materials based on Regional business data by Statistics Finland. The data contained industries' NACE affiliation, the value of bought package materials and total turnover of the companies included in each NACE class. The data did not allow identification of specific packaging material. Measured in monetary terms, 95% of package materials were bought by the 362 industries already included in the compiled accounts and 5 industries included to RINKI register but excluded from the sample. There were, however, 142 industries, the representatives of which were not included to RINKI customer register at all. Their share of the reported purchases of package materials represented 5% of the total value. This missing amount of packaging should hence be added on top of the above figures generated by using the RINKI data.

4.3.2.2.2 Packaging imported through online shopping from abroad and private imports

The COVID-19 pandemic in 2020 effectively guided consumers to online shopping increasing the online purchasing of goods by approx. 20% from previous year (Traficom 2021). The total turnover of e-commerce in Finland was 11.8 billion euros, the turnover in Sweden being 21,3 and Germany 132 billion euros (Paytrail 2020).

In the interest of packaging, the focus is on e-commerce of goods from abroad. The domestic e-commerce was considered to be included in the national producer responsibility statistics.

The amount of packaging imported by online shopping from abroad was estimated by utilizing the turnover and reported packaging amounts of importing companies covered by producer responsibility statistics. The results were scaled by the proportion of the companies' industry share to correspond to the entire industry. With the value of online purchases obtained from the regional entrepreneurial activity data for NACE 47910, a multiplier (kg/€) for the amounts of packaging materials per monetary value was generated. This information was utilized to calculate the entire packaging quantities entering Finland via online shopping from abroad (Table 26). The turnover of online purchases of retail products by consumers living in Finland in 2020 was approximately 5.2 billion euros, from which 39% were bought from online stores abroad. The turnover of consumer products purchased from abroad was 2.04 billion euros. Of this, approx.1.1 billion were from the EU, 0.54 billion from China and 0.42 billion from other non-EU countries. The estimates were based on consumer survey done in March 2020 by Finnish Commerce Federation (Kurjenoja 2022). In Finland most online purchases from abroad were made from Germany, China, Sweden and Great Britain (Postnord 2020).

The total amount of packaging entering Finland by online shopping from abroad was 11 000 tonnes. This is in line with the estimate of 2012, when the turnover of online shopping from abroad and the flow of packaging material arriving with it were both estimated to be half of the size, 5 000 tons and 1.04 billion euros (Jokinen et al. 2015). Packaging in regards of online alcohol purchases from abroad was approx. 4 000 tonnes, being 35% of the total (estimated similarly to private imports below). However, according to Paytrail (2020) only 4% of the overall online purchases from abroad were alcohol.

Table 26. The turnover of e-commerce and goods from abroad.

Subject	billion euros
total turnover of e-commerce	11.8
turnover of good from abroad	2.04

The assessment of the volume of packaging brought in by private imports applies only to alcohol. The Finnish Institute for health and welfare (THL) reports the quantities and types of alcohol imported annually through passenger imports and e-commerce. In 2020 the amount of alcohol imported through private imports was 29,4 million litra's and the product distribution can be found in Table 27. The private imports of alcohol were halved in 2021 (THL).

Table 27. The amounts of different beverages purchased in 2020 (in million liters).

Beverage group	amount (million liters)
beer	13.3
ciders and mild mixed drinks	7.7
mild vines	4.8
fortified wines and strong mixed drinks	1
spirits	2.6

The estimate of the distribution of alcoholic beverages in different packages is based on PALPA's confidential statistics. The packaging volumes of the beverages were estimated based on Palpa's most common packaging sizes and material information. The beverage cans were presumed to be bought in cardboard packaging of 24 cans (Jokinen et al. 2015). Half of the private imports of wine were presumed to be imported in cardboard boxes. The average package weights used in the estimate are shown in Table 28. The amounts of packages imported through private imports of alcohol was approx. 9 400 tons in total. The amount corresponds to the estimate made for 2012 of 9 000 tons (Jokinen et al. 2015).

Table 28. The average package weights used (Palpa 2022a, Rinki 2022, Jokinen et al. 2015).

Packaging type	average weight (g)
deposit-based glass bottle	340
other glass bottle	470
aluminium can	14
plastic bottle	30
wine box	120 cardboard, 40 plastic
cardboard carrier box for wine (12 bottles)	300
cardboard carrier box for cans (24 cans)	150

4.3.2.3 The use of packages, the intermediate use and final use

The packaging is either being placed on the market for the first time or taken for reuse. Packaging is used in e.g. primary production, various industries, construction and demolition, agriculture and municipalities. The value of packages purchased by different industries was obtained from input-output data (Statistics Finland). Data sources and types concerning the use of packaging are shown in Figure 29.

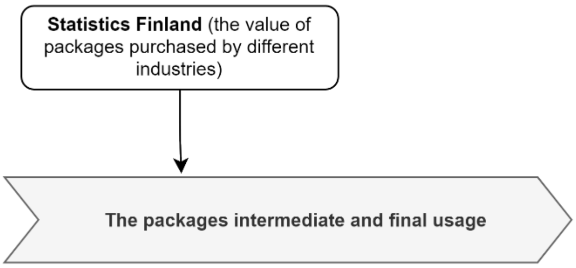

Figure 29. The data sources (in bold) and data type (in parenthesis) concerning the use of packaging.

4.3.2.4 Generation of packaging waste

Packaging waste applies to packaging and packaging material waste, excluding the waste from the manufacture of packaging (1029/2021). In principle, the amount of packaging waste generated equals the amount placed on the market. Exception to this is the packaging purchased by households for their own use (such as cardboard boxes and plastic bags) which cannot be fully separated from packaging waste subject to producer responsibility as it is likely that households return these packages to separate collection even though they are not intended to be placed there. In any case, the generated packaging waste from households' end-of-life packages acquired for their own use ends up in either separate collection or mixed municipal solid waste (MSW).

In 2020, the total amount of packages bought by households was approx. 32 000 tonnes (paper and cardboard 16 000 tonnes, plastics 14 000 tonnes and glass 2 000 tonnes). The number of packages purchased was estimated using the value of packaging bought by households obtained from input-output statistics (Statistics Finland). These numbers were not included into the estimate of packages released on the market. The data sources concerning the generation of packaging waste are presented in **Error! Reference source not found.**.

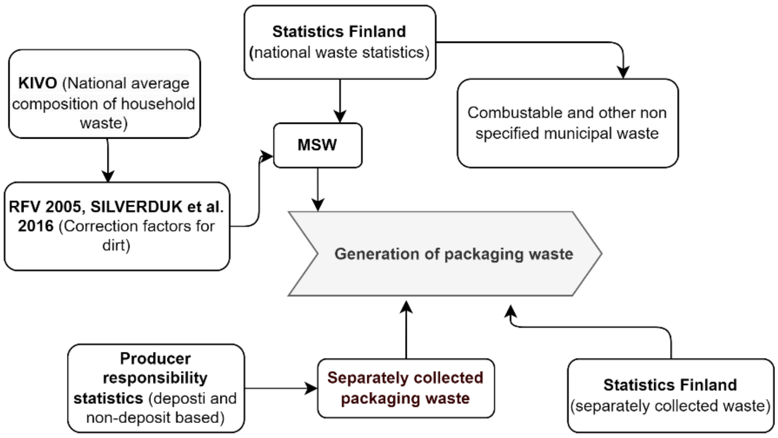

Figure 30. The data sources concerning the generation of packaging waste.

4.3.2.4.1 Separate collection of packaging waste

The separately collected amount can be obtained from the producer responsibility statistics on waste collection. Producer responsibility obliges the manufacturer and importer to organize and finance the waste management and recycling of the products they place on the market. The obligations are full filled by producer responsibility organizations. There are 1 900 collection points - organized by RINKI on behalf of producer responsibility organizations - for the collection of household packaging waste, the national collection network handles the collection of packaging waste from companies and municipalities, and the industry enters into its own contracts for the collection of packaging waste on site. There is also a deposit-based producer responsibility system for beverage packaging. Reuse of beverage packaging only applies to 0,33-liter brown beer bottles, which are washed and refilled. The quantity of reused bottles can be obtained from producer responsibility statistics.

The amount of municipal separately collected waste can be obtained from Statistics Finland's database. In 2020 the amount was lower than the amount of mixed MSW, 1 524 000 and 1 659 000 respectively. The amount contains also other waste than packages, for example newspapers and thus the amount of packaging waste collected can be more accurately obtained from the producer responsibility statistics.

4.3.2.4.2 Packaging waste in mixed MSW

The amount of packaging waste in mixed MSW needs to be estimated as precise data are not available. The amount of mixed MSW (EWC 200301) was 1 659 000 tonnes in 2020 (Statistics Finland 2020). It has been estimated that approx. 65% of municipal waste is generated by households and 35% by administration, service and business sector (Salmenperä et al. 2016). The amount of packaging in mixed MSW was estimated by using consistency analysis on mixed household waste (KIVO) as data on the composition of MSW from administration, service and business sector is not currently available. Most of it is estimated to be generated in hotel, restaurant and transport industries (Karppinen et al. 2021). The estimated amount of packaging in mixed MSW was corrected by using estimates made in Sweden about the amount of dirt in the packaging (RFV 2005, Silfverduk et al. 2016). The assessment was made with two different correction factors due to their difference (Table 29) and the final estimates were made with the factors from 2005. The values of 2016 would give such high packaging quantities, which greatly exceed the quantity released on the market, thus making the estimate unrealistic. A similar study has not yet been conducted in Finland.

Table 29. The different correction factors for dirt (RFV 2005, Silfverduk et al. 2016).

Packaging material	correction factor for dirt (RFV 2005)	correction factor for dirt (Silfverduk et al. 2016)
Paper & cardboard	0.56	0.74
Plastic	0.56	0.83
Metal	0.65	0.86
Glass	0.95	0.8
Wood	0	0

The packaging waste in MSW of combustible waste (EWC 191210) and in not otherwise specified municipal waste (EXC 200399), approx. 233 000 tonnes in 2020 are not assessable. The combustible waste is generated from unrecyclable mixed waste and from the reject streams of recycling systems. (Pöyry 2015)

4.3.2.5 Packaging waste received for secondary material production

This applies to quantities of packaging waste which, after collection and possible pre-treatment, are taken to a recycling facility for recycling. The reported recycled amount is calculated from the measured weight of the packaging waste entering a recycling operation. With the amendment to the EU Directive on packaging and packaging waste (EU) 2018/852 the reject generated prior is not to be included in the reported recycled amount of packaging waste. In the recycling of multimaterial packaging, coating materials like plastic and aluminium can also be recovered and recycled. (Salste 2011 in Leikas 2020) Each material in a multimaterial packaging shall be counted and declared for, if the proportion of the material exceeds 5% of the total weight of the package. If the proportion is below 5%, the total weight of the package is calculated and reported for the main material of the package. The data sources concerning packaging waste received for secondary material production are presented in Figure 31.

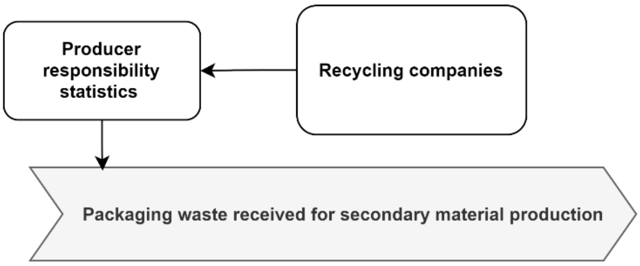

Figure 31. The data sources concerning packaging waste received for secondary material production

4.3.2.6 **End-products: produced secondary materials**

The material losses during recycling packaging waste into new products by physical or chemical transformation processes does not affect the amount of waste reported as being recycled. The amount of recycled material produced reflects what the existing recycling systems are capable to recycle and thus whether the packaging is recyclable or not. The data for produced secondary materials can be obtained from the producer responsibility statistics and directly contacting recycling companies. The assessment of this stage is not in the scope of this project. The data sources concerning end-products produced from secondary materials are presented in Figure 32.

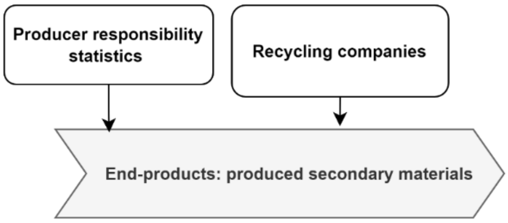

Figure 32. The data sources regarding end-products produced from secondary materials.

4.3.2.7 **Summary**

The data sources of the life-cycle stages of packaging are summarized in Figure 33.

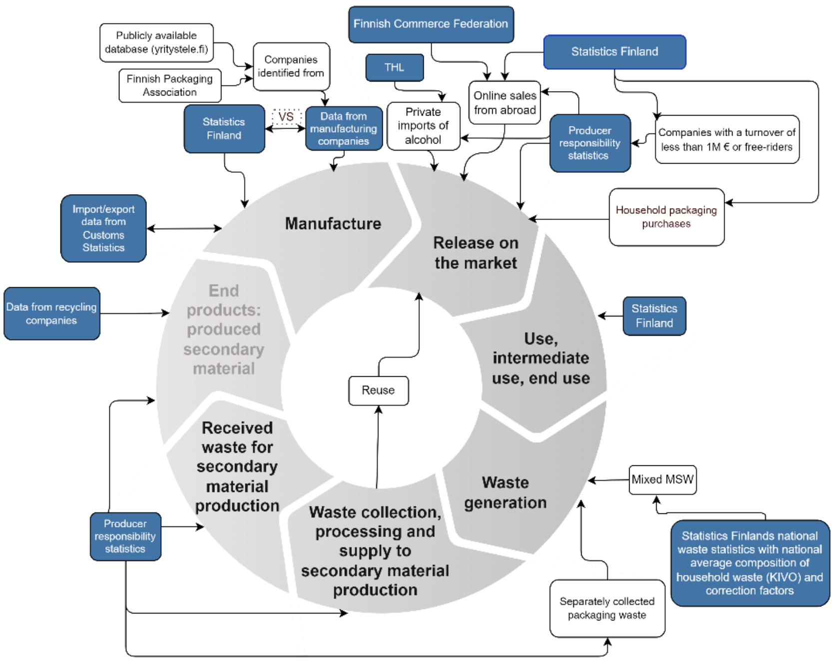

Figure 33. The data sources (blue) and data types (white) on different life-cycle stages of packaging. The part of the circle in light grey is not in the scope of the project.

4.4 **Material-specific packaging flow estimations**

Findings of data availability and data gaps by chosen materials.

4.4.1 Paper and cardboard

Paper and cardboard packaging is either of mono- or multimaterial. Multimaterial packaging must contain more than 50% by weight of either paper or cardboard. The additional materials are most likely either metals, like aluminium and tin or plastic (Finnish national regulation on packaging and packaging waste 518/2014).

In the multimaterial cardboard packaging, the surface of the cardboard can be plastic-coated, or the plastic film can be laminated between the layers. The plastic helps to prevent the passage of grease, gas and water vapor. (Suomen Aaltopahviyhdistys ry 2020)

4.4.1.1.1 Manufacture of packaging

In 2020 there were roughly 60 manufacturers of paper and cardboard packages in Finland (NACE code 1721) (Statistics Finland 2022). Data on the amount of paper and cardboard packaging manufactured in volume (kg) and their value of sales were obtained from the Official Statistics Finland database. The amount of paper and cardboard packaging manufactured in Finland in 2020 was approximately 357 000 tonnes.

The data obtained from Statistics Finland were compared with the results of a survey to packaging manufacturers. The survey covered approx. 90 percent of the turnover of Finnish paper and cardboard manufacturing companies with a NACE 17211 and over 93 percent with NACE 17212. The survey also covered companies that had a different NACE and manufacture paper and cardboard packaging.

The results were scaled to reflect the entire industry by the respondents' share of the industry's turnover. The amount of paper and cardboard packaging manufactured in 2020 was 198 000 tonnes. From these approx. 85 percent were of monomaterial and the rest of multimaterial. The multimaterial packaging contained plastic in addition to paper and cardboard, the polymer types mentioned being PE, PP and PET. The amount of reject from raw material in the production of packaging was approximately 6 percent. Packaging waste from manufacture is mainly recycled. The manufactured packaging contained approximately 26 percent recycled material. According to the survey, approximately 1,2 billion manufactured paper and cardboard packaging were packaging subject to the SUP directive (90–93% coverage of the paper & cardboard manufacturing industry). The companies were able to state the amount in both tonnes and in the number of units, the latter required by the Directive.

48 000 tonnes of paper and cardboard packaging were imported and 7 000 tonnes exported from Finland in 2020 (the Finnish customs database). The data applies to empty packages. The amount of paper and cardboard packaging manufactured in Finland according to the survey and the amount of imported and exported empty packages are presented in Table 30.

Table 30. Paper and cardboard packaging manufactured in Finland in 2020, including packaging export and import (in tonnes).

Paper and cardboard packaging	amount/ t
packaging manufacturers	198 000
- monomaterial	- 167 000 (85%)
- multimaterial	- 30 000 (15%)
import	48 000
export	7 000
total (manufacture+import-export)	**238 000**

4.4.1.1.2 Packages released on the market

Based on the method developed in this study, the total estimate of the fibre packaging placed on the market in 2020 was about 358 000 tonnes (for industry-specific details, see Supplementary material 9. Packaging volumes reported by producer responsibility organizations (based on RINKI data) covered 76% of the packaging placed on the market (272 000 tonnes), 24% (86 000 tonnes) being placed by free-riders and companies not obliged to producer responsibility. An estimated 10% of this was multimaterial packaging and 90% monomaterial. Multimaterial packaging contained an estimated of 14% of plastic and 0.4% of metal. (Jokela 2021)

In addition to above fibre packaging entered the market via online shopping from abroad, private imports and households purchasing packaging for their own use. The amount of cardboard packaging imported via online shopping from abroad was estimated at 8 000 tonnes. 306 tonnes of cardboard were estimated to have arrived to Finland via private imports of alcohol. The estimate is based on the Finnish Institute for health and welfare's (THL) data on the quantity and quality of alcohol imports, the distribution of alcoholic beverages in different packages (PALPA) and on average packaging sizes (Rinki 2022, Heinonen 2015, Jokinen et al. 2015). The assumption was made that cardboard is used in wine packaging and group packaging of bottles and cans. The beverage cans were estimated to be bought in cardboard packaging of 24 cans (Jokinen et al. 2015). Half of the private imports of wine were estimated to be imported in cardboard boxes.

Majority of paper and cardboard packages (61%) were business packages. Those include the upscaled estimate on business packages reported to RINKI. Consumer packages (39%) include upscaled estimate on consumer packages reported to RINKI, online sales from abroad and private imports of alcohol.

Altogether the volume of paper and cardboard on the market was 367 000 tonnes. The corresponding number in the producer responsibility statistics was 338 000 tonnes (Pirkanmaa ELY-Centre). The amount of packaging released on the market from outside the reported numbers was estimated to be 94 000 tonnes (26%) in this study. In the producer responsibility statistics, the corresponding estimate was 80 000 tonnes (Jokela 2021). In 2012 the estimate was 60 000-70 000 tonnes (Jokinen et al. 2015). The amount of fibre packages released on the market are presented in Table 31.

Table 31. Paper and cardboard packaging released on the market in Finland in 2020 (in tonnes).

Paper & cardboard packaging	amount/ t
packages released on the market	358 000
- reported volumes	- 272 000
- free-riders and < 1M companies	- 86 000
online sales from abroad	8 000
private imports of alcohol	306
total	**367 000**

4.4.1.1.3 Distribution of packaging waste to separate collection and municipal solid waste (primary waste)

According to the producer responsibility statistics the amount of separately collected paper and cardboard packaging waste in 2020 was 336 000 tonnes. The amount of municipal separately collected paper and cardboard waste was 484 000 tonnes (Statistics Finland). The amount contains also other waste than packages, for example newspapers which explains the larger amount.

The amount of paper and cardboard packaging in the mixed MSW was 75 000 tonnes in 2020. The percentage of paper and cardboard packaging in MSW is estimated to be 8,1% from which 1,2% were of paper, 1,7% of cardboard and 5,4% of carton. 26 000 tonnes of the mixed MSW are estimated to be generated by service industries (35%) and 49 000 tonnes by households (65%). Paper and cardboard packaging in the MSW was calculated based on national estimates on MSW composition and adjusted with a correction factor for dirt (RFV 2005). The

MSW ends up mainly in incineration. The amount of fibre packaging waste is presented in Table 32.

Table 32. Paper and cardboard packaging waste in Finland in 2020 (in tonnes).

Paper and cardboard packaging waste	amount/ t
Separate collection	336 000
mixed MSW	75 000
- service industry	- 26 000 (35%)
- households	- 49 000 (65%)
total	**411 000**

The amount of paper and cardboard waste generation in litter and in use in e.g. small-scale household combustion were impossible to determine, because there were no data available to identify the latter, and although information was available on the amount of street sweeping waste from the companies carrying out the activities, its composition remained unknown. However, the contribution of these flows to the overall flow of paper and cardboard in the Finnish economy is likely small.

4.4.1.1.4 Packaging waste received and processed in secondary material production

Paper has been recycled in Finland since the 1930s (The Finnish Packaging Association 2017). The amount of recycled packaging waste is based on weighings and the current recycling rate is calculated before the material enters the recycling process. The amount of recycling is estimated to be reduced by up to 11% in the recycling process, of which 0.4% is bale wire and the rest is plastic, metal and other contaminants. (Statistics Finland 2019). According to the Statistics Finland's data the amount of paper and cardboard recycled in 2020 was 484 000 tonnes, 5 000 tonnes were incinerated. This includes also other products than packaging e.g. newspapers. The amount of packaging recycled in 2020 according to the producer responsibility was 332 000 tonnes, 6 000 tonnes were incinerated. The amount of fibre packaging waste recycled and incinerated is presented in Table 33.

Table 33. Paper and cardboard packaging waste recycled and incinerated in Finland in 2020 in tonnes (producer responsibility statistics).

Paper & cardboard packaging waste	amount/ t
recycled	332 000
incinerated	6 000
total packaging waste recycled +incinerated	**338 000**

4.4.1.1.5 Summary

The summary of fibre packaging flow in tonnes during different life cycle stages is presented below in Table 34.

Table 34. Paper and cardboard packaging flow in different life cycle stages in Finland in 2020 (in tonnes)

Life cycle stages	Paper&cardboard packaging/t
Manufacture +import-export	238 000
Release on the market	367 000
Separate collection	336 000
Packages in mixed MSW	75 000
Waste generation estimate (MSW+ producer resp.)	411 000
Received for secondary material production	332 000
Energy recovery (producer resp.)	6 000

4.4.2 Plastics

Plastic packaging can be either of mono- or multimaterial. The recyclability relates to the materials used, cleanliness and color of the packaging. Of the plastic grades, for example, LDPE, HDPE, PP and PET are recyclable, while PVC is not. The plastics used in corrugated cardboard packaging are polyethylene (PE), Polyethylene terephthalate (PET) or polypropene (PP) (Suomen Aaltopahviyhdistys ry 2020). Multimaterial packaging, most commonly used in food packaging that require barrier properties, are problematic to recycle. Multimaterial packaging containing plastic and other material such as cardboard or paper can be recycled only if the materials are separated. Monomaterial clear plastic packaging is best for recycling. Black or dark grey plastic packaging cannot be easily separated with current sorting technology and ends up in energy production. (Suomen Uusiomuovi Oy 2018)

Plastic packaging waste contains both deposit and non-deposit-based packaging. Producer responsibility organization Suomen Uusiomuovi Oy is responsible for non-deposit-based plastic packaging. Palpa or other similar operators are responsible for organizing the obligations concerning the plastic beverage packaging under the deposit return scheme. (Statistics Finland 2019). The deposit-based plastic bottles are monomaterial and made of PET.

Finland achieves its recycling targets well in regards of deposit-based beverage plastic packaging as 90% of these are being recycled. The recycling of other plastic packaging is of concern, with the recycling rate of 42% in 2019 and target being 50% for 2025.

4.4.2.1.1 Manufacture of packaging

There were about 50 companies manufacturing plastic packages in Finland in 2020 (NACE 2222) (Statistics Finland 2022). Data on the amount of plastic packaging manufactured in volume (kg or pieces) and their value of sales were obtained from Statistics Finland database. The number of packages were converted to mass using average package weights calculated from the Finnish customs database. The amount of plastic packaging manufactured in Finland in 2020 was approximately 86 000 tonnes.

The data obtained from Statistics Finland were compared with the results of a survey to packaging manufacturers. The respondents to the survey accounted for 96 percent of the turnover of Finnish plastic packaging manufacturing companies with a NACE 22220. The results were scaled to reflect the entire industry by the respondents' share of the industry's turnover. Information was also collected from companies with a different NACE but who also manufacture packaging.

The amount of plastic packaging produced in 2020 was 123 000 tonnes. From these approx. 80 percent were of monomaterial and 20 percent of multimaterial. The multimaterial plastic packaging mainly consisted of several different plastics and about 3 percent contained paper or cardboard. Polyethylene (PE) was the most mentioned polymer type used in plastic packaging but also PP, PA, ESP and PET for example got mentioned. The manufactured packaging contained approximately 10 percent recycled material. EU legislation prevents the use of recycled plastic in the food packaging industry and this was part of the reason for the low use of recycled plastic in packaging manufacturing.

About 2 percent of the manufactured plastic packaging was packaging subject to the SUP directive. The amount was stated by the companies in tonnes instead of the number of units required by the Directive.

65 000 tonnes of plastic packaging were imported and 17 000 tonnes were exported to/from Finland in 2020 (the Finnish customs database). The data applies to empty packages. PET- beverage bottles are being manufactured and filled in brewing companies. The amount of plastic packaging manufactured and the amount of empty packages imported and exported to Finland are presented in Table 35.

Table 35. Plastic packaging manufactured in Finland in 2020, including packaging export and import (in tonnes).

Plastic packaging	amount/ t
packaging manufactures	123 000
- mono material	- 98 000 (80%)
- multi material	- 25 000 (20%)
import	65 000
export	17 000
total (manufacture+import-export)	**171 000**

4.4.2.1.2 Packages released on the market

Based on the method developed in this study, the total estimate of the plastic packaging placed on the market in 2020 was about 162 000 tonnes (for industry-specific details, see Supplementary material 9). Packaging volumes reported by producer responsibility organizations (based on RINKI and PALPA data) covered 84% (136 000 tonnes) of the packages placed on the market, 16% (26 000 tonnes) being placed by free-riders and companies not obliged to producer responsibility. 4 000 tonnes entered the market in multimaterial packaging with cardboard (Jokela 2021).

In addition to above plastic packaging enters the market via online shopping from abroad and private imports The amount of plastic packaging imported via online shopping from abroad was estimated at 2 000 tonnes. 29 tonnes of plastic were estimated to have arrived to Finland via private imports of alcohol. The estimate is based on the Finnish Institute for health and welfare's (THL) data on the quantity and quality of alcohol imports, the distribution of alcoholic beverages in different packages (PALPA) and on average packaging sizes (Rinki 2022, Jokinen et al. 2015). It was assumed that plastic is used in wine packaging and in some spirits.

Majority of plastic packages (68%) were consumer packages. Those include the upscaled estimate on consumer packages reported by RINKI, beverage package volume reported by Palpa, online sales from abroad and private imports of alcohol. Business packages (32%) include the upscaled estimate on business packages reported to RINKI.
Altogether the volume of plastics packaging on the market was 164 000 tonnes. The corresponding number in the producer responsibility statistics was 157 000 tonnes (Pirkanmaa ELY Centre). The amount of packaging released on the market from outside the reported numbers was estimated to be 29 000 tonnes (17%) in this study. The amount of plastic packaging released on the market is presented in Table 36.

Table 36. Plastic packaging released on the market in Finland in 2020 (in tonnes).

Plastic packaging	amount/ t
packages released on the market	162 000
- reported volumes	- 136 000
- free-riders and <1 M € companies	- 26 000
online sales from abroad	2 000
private imports of alcohol	29
total	**164 000**

4.4.2.1.3 Distribution of packaging waste to separate collection and municipal solid waste (primary waste)

The regional separate collection of plastic packaging waste from households in Finland started in 2016. Prior to this, majority of plastic packaging ended up in the mixed MSW. The separately collected amount of plastic packaging waste can be obtained from the producer responsibility statistics. The legislation for light PET bottle deposit-based return scheme entered into force in 2008 (Palpa 2022) and the collection points only allow the return of PET bottles so that the bottles can be recycled. A separate collection of other post-consumer plastic packaging waste was not introduced until 2019 (Plastin). According to the producer responsibility statistics the estimated amount of separately collected plastic packaging waste in 2020 was 62 000 tonnes. The amount of municipal separately collected plastic waste was 93 000 tonnes (Statistics Finland 2020).

The estimated amount of plastic packaging in the mixed MSW was 107 000 tonnes in 2020. The percentage of plastic packaging in MSW is estimated to be 11,5% of which 6,3% hard plastic and 5,2% plastic film. 37 000 tonnes of the mixed MSW are estimated to be generated from service industries (35%) and 70 000 tonnes from households (65%). Plastic packaging in the MSW was calculated based on the national estimates on the composition of MSW and adjusted with a correction factor for dirt (RFV 2005). The MSW ends up mainly in incineration. The amount of plastic packaging waste is presented in Table 37.

Table 37. Plastic packaging waste in Finland in 2020 (in tonnes).

Plastic packaging waste	amount/ t
separate collection	62 000
mixed MSW	107 000
- service industry	- 37 000 (35%)
- households	- 70 000 (65%)
total	169 000

4.4.2.1.4 Packaging waste received and processed in secondary material production

Plastic packaging waste can be recycled either mechanically or chemically. With chemical recycling it is possible to recycle contaminated plastic waste streams. In addition, chemical recycling can extend the recycling of plastic. The plastic can only undergo mechanical recycling four times, but after that, the recycled plastic can still be processed by chemical recycling. (Roschier et al. 2019.)

The amount of consumer packaging waste entering recycling is based on weighing's from Fortum's plastic Refinery in Riihimäki, which handles all separately collected consumer plastic packaging waste in Finland. The company also processes part of the plastic waste generated by industry, making it into recycled plastic granulate as an industrial raw material. At the end of 2019, another company Lassila & Tikanoja opened a plastic refinery in Merikarvia, Muoviportti.

The amount of plastic packaging waste by industry is obtained from the producer responsibility organization Suomen Uusiomuovi Oy's reception terminals and contract partners. Also this data is based on weighing's. The waste is weighed at the entry of mechanical sorting plant. In case the point of weighing was to be moved to a later stage in the recycling process, to prior granulation or flake preparation, the amount of reject in consumer packaging is presumed to be approx. 25% and in business packaging 5%. There is virtually no reject from plastic beverage packaging under the deposit return scheme. (Statistics Finland 2019).

Most of the collected agricultural plastics goes to energy production and only about one-fifth is recycled. The challenges are the difficulty of separating different plastics and their dirtiness (Ojanperä 2019). According to the Statistics Finland the amount of plastic recycled in 2020 was 57000 tonnes, 36000 tonnes were incinerated or disposed differently. This includes also other products than packaging. The amount of packaging recycled in 2020 according to the producer responsibility statistics was 41 000 tonnes, 115 000 tonnes were incinerated. The amount of plastic packaging waste recycled and incinerated is presented in Table 38.

Table 38. Plastic packaging waste recycled and incinerated in Finland in 2020 in tonnes (producer responsibility statistics).

Plastic packaging waste	amount/ t
recycled	41 000
incinerated	115 000
total packaging waste (recycled +incinerated)	**156 000**

4.4.2.1.5 Summary

The summary of plastic packaging flow in tonnes during different life cycle stages is presented below in Table 39.

Table 39. Plastic packaging flow in different life cycle stages in Finland in 2020 (in tonnes).

Life cycle stages	Plastic packaging/t
Manufacture +import -export	171 000
Release on the market	164 000
Separate collection	62 000
Packages in mixed MSW	107 000
Waste generation estimate (MWS+ separate collection)	169 000
Received for secondary material production	41 000
Energy recovery (producer resp.)	115 000

4.4.3 Metals

Metal packaging are made of aluminium, steel, tin or combinations of these. The most common material is tin, which is used extensively in the food industry. (The Finnish packaging association 2019)

Metal have been recycled in Finland since the 1930's (The Finnish Packaging Association 2017).

Metal packaging waste contains both deposit return scheme based and non-deposit-based packaging. The beverage metal packaging is mainly of aluminium.

4.4.3.1.1 Manufacture of packaging

Data on the amount of metal packaging manufactured in volume (kg or pieces) and their value of sales were obtained from the Statistics Finland database. Piece quantities were converted to mass quantities using average package weights calculated from the Finnish customs database, RINKI average metal package weights and VAHTI compliance monitoring system. The amount of metal packaging manufactured in Finland in 2020 was estimated to be 39 000 tonnes.

The data obtained from the Statistics Finland were compared with the results of a survey to packaging manufacturers. The survey covered 90 percent of the turnover of Finnish metal packaging manufacturing companies. The results of the survey were scaled by the proportion of the company's industry share to correspond to the entire industry. The amount of metal packaging both aluminium and ferrous metal manufactured in 2020 was 31 000 tonnes. From these approx. 80 percent were of aluminium and 20 percent of ferrous metal. The amount of reject from raw material in the production of packaging was approximately 3-15 percent.

The amount of metal packaging imported or exported to and from Finland were obtained from the Customs data base (Uljas). The amount of metal packaging imported into Finland in 2020 was 17 000 tones, the exported amount being 13 000 tonnes. The data applies to empty packages. The amount of metal packaging manufactured in Finland and the amount of empty packages imported to and exported from Finland are presented in Table 40.

Table 40.Metal packaging manufactured in Finland in 2020, including packaging export and import (in tonnes).

Metal packaging	amount/ t
packaging manufacturers (survey)	31 000
import	17 000
export	13 000
total (manufacture+import-export)	**35 000**

4.4.3.1.2 Packages released on the market

Based on the method developed in this study, the total estimate of the metal packaging placed on the market in 2020 was about 56 000 tonnes (for industry-specific details, see Supplementary material 9). Packaging volumes reported by producer responsibility organizations (based on RINKI and PALPA data) covered 89% (50 000 tonnes) of the packaging placed on the market, 11% (6 000 tonnes) being placed by free-riders and companies not obliged to producer responsibility.

In addition to above metal packaging entered the market via online sales from abroad and private imports of alcohol. The amount of metal packaging imported via online shopping from abroad was estimated at 159 tonnes.

820 tonnes of aluminium was estimated to have arrived to Finland via private imports of alcohol. The estimate is based on the Finnish Institute for health and welfare's (THL) data on the quantity and quality of alcohol imports, the distribution of alcoholic beverages in different packages (PALPA) and on average packaging sizes (Rinki 2022, Jokinen et al. 2015). The estimate applies to aluminium cans, not bottle caps.

Majority of metal packages (62%) were consumer packages. Those include the upscaled estimate on consumer packages reported by RINKI, beverage package volume reported by Palpa, online sales from abroad and private imports of alcohol. Business packages (38%) include the upscaled estimate on business packages reported to RINKI.

Altogether the volume of metal packaging on the market was 57 000 tonnes. The corresponding number in the producer responsibility statistics was 54 000 tonnes (Pirkanmaa ELY Centre). The amount of packaging released on the market from outside the reported numbers was estimated to be 7 000 tonnes (12%) in this study. The amount of metal packaging released on the market is presented in Table 41.

Table 41. Metal packaging released on the market in Finland in 2020 (in tonnes).

Metal packaging	amount/ t
Packages released on the market	57 000
- reported volumes	- 50 000
- free-riders and <1 M € companies	- 6 000
online sales from abroad	159
private imports of alcohol	820
total	**57 000**

4.4.3.1.3 Distribution of packaging waste to separate collection and municipal solid waste (primary waste)

According to the producer responsibility statistics the amount of separately collected metal packaging waste in 2020 was 44 000 tonnes, 23 000 tonnes were of ferrous metal and 21 000 of aluminium. The amount of municipal separately collected metal waste was 129 000 tonnes. The amount contains also other waste than packaging which explains the larger amount.

The amount of metal packaging in the mixed MSW was 14 000 tonnes in 2020. The percentage of metal packaging in MSW is estimated to be 1,5% of which 0,5% is aluminium and 0,8% other metal packaging (KIVO 2021). 5 000 tonnes of the mixed MSW are estimated to be generated from service industries (35%) and 9 000 tonnes from households (65%). Metal packaging in the MSW was calculated based on the national estimates on the composition of MSW and adjusted with a correction factor for dirt (RFV 2005). The metal in MSW ends up mainly in recycling. Metals are recovered from MSW before incineration or afterwards from the slag. The amount of metal packaging waste is presented in Table 42.

Table 42. Metal packaging waste in Finland in 2020 (in tonnes).

Metal packaging waste	amount/ t
separate collection	44 000
mixed MSW	14 000
- service industry	- 5 000 (35%)
- households	- 9 000 (65%)
total	**58 000**

4.4.3.1.4 Packaging waste received and processed in secondary material production

Information on metal packaging waste was obtained from the producer organizations Mepak-kierrätys Oy and Palpa. The uncertainty of the data results from the fact that not all municipalities and private companies report their collection data to Mepak. In 2012 Mepak- Oy's information was based on the billing information of metal packaging waste pre-processors (crushers), consumer packaging collection and incineration plant slag sorting companies. In addition, information was supplemented from scrap shops, which supplied scrap metal directly to steel mills and for export. The data from the pre-processors were based on weighing's. The data for incineration plants were also based on weighing's, and the share of metal packaging in the total amount of metal was determined both by calculation and analysis.

Palpa's information came from recycling facilities and was based on weighing's (Jokinen et al. 2015.) The majority of recycled metal packaging waste is non-deposit based. The estimated amount of reject in deposit-based metal packaging waste is 1- 3%. (Statistics Finland 2019).

According to the Statistics Finland the amount of metal recycled in 2020 was 129 000 tonnes, 7 tonnes were incinerated. This includes also other products than packaging. The amount of packaging recycled in 2020 according to the producer responsibility was 44 000 tonnes. The recycling percentage in 2020 was 77% (calculated from the amount of packages released on the market and the amount recycled). The amount of metal packaging waste recycled is presented in Table 43.

Table 43. Metal packaging waste recycled in Finland in 2020 (in tonnes).

Metal packaging waste	amount/ t
total packaging waste recycled	44 000

4.4.3.1.5 Summary

The summary of metal packaging flow in tonnes during different life cycle stages is presented below in Table 44.

Table 44. Metal packaging flow in different life cycle stages in Finland in 2020 (in tonnes).

Life cycle stages	metal packaging/t
Manufacture (+import-export)	35 000
Release on the market	57 000
Separate collection	44 000
Packages in mixed MSW	14 000
Waste generation estimate (MSW+ separate collection)	58 000
Received for secondary material production	44 000

4.4.4 Wood

Wood packaging includes e.g. pallets, barrels, rods and packaging supports, crates, boxes and cable reels. The wood packages contain mainly wood and in small amount of metal nails etc. to hold the packages together. The main users of wood packaging are trade and industry.

4.4.4.1.1 Manufacture of packaging

In 2020 there were about 110 manufacturers of wood packages in Finland (NACE 1624) (Statistics Finland 2022). Data on the amount of wood packaging produced in volume (kg or pieces) and its value of sales were obtained from the Statistics Finland database. The number of packages were converted to mass using average package weights obtained from different websites[2] with information about pallets and their dimensions. The amount of wood packaging manufactured in Finland in 2020 was approximately 475 000 tonnes.

The data obtained from Statistics Finland were compared with the results of a survey to packaging manufacturers. The survey reached 29 percent of the turnover of Finnish wood packaging manufacturing companies, with the respondents accounting for 11 percent. The results of the survey were scaled to reflect the entire industry by the respondents' share of the industry's turnover. The companies changed the unit quantities produced into mass quantities, which introduced uncertainty into the answers. The answers were based on the raw material used in production and the reject. The amount of wood packaging produced in 2020 was 176 419 tonnes. The wood packaging contained small percent of metal. The average amount of reject from raw material in the production of packaging was 4 percent (0–9%).

38000 tonnes of wood packaging were imported and 51 000 tonnes were exported to Finland in 2020 (the Finnish customs database). The data applies to empty packages. The amount of wood packaging manufactured in Finland and the amount of empty packages imported to and exported from Finland are presented in Table 45.

Table 45. Wood packaging manufactured in Finland in 2020, including packaging export and import (in tonnes).

Wood packaging	amount/ t
packaging manufacturers (survey)	176 000
import	38 000
export	51 000
total (manufacture+import-export)	**164 000**

[2] https://www.logistiikanmaailma.fi/logistiikan-toimijat/varastointi/varastotyypit-ja-tekniikka/kuormalava/, Lavakaulus - THTT

4.4.4.1.2 Packages released on the market

Based on the method developed in this study, the total estimate of the wood packaging placed on the market in 2020 was about 289 000 tonnes (for industry-specific details, see Supplementary material 9). Packaging volumes reported by producer responsibility organizations (based on RINKI data) covered 96% (276 000 tonnes) of the packaging placed on the market, 4% (13 000 tonnes) being placed by free-riders and companies not obliged to producer responsibility. In addition to this, 63 000 tons of repaired wooden pallets are added to this number. They are counted as recycled and according to the European Commission calculation rule they are also added to the base number of recycling i.e. the amount of packages released on the market.

The amount of wood packaging imported through online shopping from abroad was estimated at 5 tons. There weren't any wood packaging entering Finland via private imports of alcohol.

Majority of wood packages (99%) were business packages. Those include the upscaled estimate on business packages reported to RINKI and the repaired pallets. Consumer packages (1%) include upscaled estimate on consumer packages reported to RINKI and online sales from abroad.

Altogether the volume of wood packaging on the market was 352 000 tonnes. The corresponding number in the producer responsibility statistics was 301 000 tonnes (Pirkanmaa ELY Centre). The amount of packaging released on the market from outside the reported numbers was estimated to be 13 000 tonnes (4%) in this study. The amount of wood packaging released on the market is presented in Table 46.

Table 46 Wood packaging released on the market in Finland in 2020 (in tonnes).

Wood packaging	amount/ t
Packages released on the market	290 000
- reported volumes	- 276 000
- free-riders and <1 M € companies	- 13 000
repaired pallets	63 000
online sales from abroad	5
total	**352 000**

4.4.4.1.3 Distribution of packaging waste to separate collection and municipal solid waste (primary waste)

According to producer responsibility statistics the separately collected amount of wood packaging waste in 2020 was 78 000 tonnes. The amount of separately collected wood waste in 2020 was 102 000 tonnes (Statistics Finland 2020).

The mixed MSW is estimated not to contain any wood packaging. The amount of wood packaging waste is presented in Table 47.

Table 47. Wood packaging waste in Finland in 2020 (in tonnes).

Wood packaging waste	amount/ t
separate collection	78 000
mixed MSW	-
total	78 000

4.4.4.1.4 Packaging waste received and processed in secondary material production

The repaired wood packaging is counted as recycled wood. The producer responsibility organization (PPK oy) collects information from producers and packaging repairing companies on the amounts repaired. Standard pallets (FIN and EURO pallets) repair requires that the company has been granted a repair permit. The volume of repaired wood packages were calculated by multiplying the number of packages by their average unit weights. (Jokinen et al. 2015).

The share of repaired wooden packaging accounted for about 2/3 of the recycling of wood packaging waste in 2016. The amount of wood packaging utilized in composting and landscaping was obtained from operators engaged in these practices and from waste facilities. (Statistics Finland 2019). The wood waste was weighed, and the share of wood packaging waste was estimated from this. All packaging waste other than recycled was counted for energy recovery (Jokinen et al. 2015).

According to the Statistics Finland the amount of wood recycled in 2020 was 78 000 tonnes, 25 000 tonnes were disposed by incineration, composting etc. This includes also other products than packaging. The amount of packaging recycled in 2020 according to the producer responsibility was 78 000 tonnes, from which 63 000 tonnes were repaired wood packaging. 223 000 tonnes of wood packaging were incinerated. The recycling percentage in 2020 was 27% (calculated from the amount of packages released on the market and the amount recycled). The amount of wood packaging waste recycled and incinerated is presented in Table 48.

Table 48. Wood packaging waste recycled and incinerated in Finland in 2020 in tonnes (producer responsibility statistics).

Wood packaging waste	amount/ t
recycled	78 000
incinerated	223 000
total packaging waste (recycled+incinerated)	**300 000**

4.4.4.1.5 Summary

The summary of wood packaging flow in tonnes during different life cycle stages is presented below in Table 49.

Table 49. Wood packaging flow in different life cycle stages in Finland in 2020 (in tonnes).

life cycle stages	wood packaging/t
Manufacture+import-export	164 000
Release on the market (including repaired pallets)	352 000
Separate collection	78 000
Packages in mixed MSW	-
Waste generation estimate (MSW+producer resp.)	78 000
Received for secondary material production	78 000
Energy recovery (producer resp.)	223 000

4.4.5 Glass

Glass packaging waste contains both deposit return scheme based and non-deposit-based packaging. Also in the deposit based system there are bottles that either goes to recycling or to reuse. Glass bottles have been reused in Finland since 1950's (Palpa 2021). Producer responsibility organization Suomen keräyslasiyhdistys is responsible for non-deposit-based glass packaging. Palpa is responsible for organizing the obligations concerning the glass beverage packaging under the deposit return scheme. (Statistics Finland 2019). There are also other deposit-based systems in place.

4.4.5.1.1 Manufacture of packaging

Glass packaging is not manufactured in Finland, so it could be assumed that all packaging is imported from elsewhere. However, according to the customs statistics, 148 tons of glass packaging was exported from Finland in 2020. The amount of glass packaging imported was 43 000 tonnes. The amount of empty glass packages imported to and exported from Finland are presented in Table 50.

Table 50. Glass packaging export and import to Finland in 2020 (in tonnes).

Glass packaging	amount/ t
import	43 000
export	148
total	**43 000**

4.4.5.1.2 Packages released on the market

Based on the method developed in this study, the total estimate of the glass packaging placed on the market in 2020 was about 92 000 tonnes (for industry-specific details, see Supplementary material 9). Packaging volumes reported by producer responsibility organizations (based on RINKI and Palpa data) covered 96% (88 000 tonnes) of the packaging placed on the market, 4% (4 000 tonnes) being placed by free-riders and companies not obliged to producer responsibility.

In addition to the above glass packaging entered the market via online shopping from abroad, private imports of alcohol and households purchasing packaging for their own use. The amount of glass packaging imported by online shopping from abroad was estimated at 322 tonnes.

5 000 tonnes of glass was estimated to have arrived to Finland via private imports of alcohol. The estimate is based on the Finnish Institute for health and welfare's (THL) data on the quantity and quality of alcohol imports, the distribution of alcoholic beverages in different packages (PALPA) and on average packaging sizes (Rinki 2022, Heinonen 2015, Jokinen et al. 2015). It was assumed that glass is used in all types of alcohol packaging. Ekopulloyhdistys takes care of the producer responsibility obligations in regards of reusable glass beverage bottles. Reusable glass packaging can be recycled approximately 33 times (Palpa 2021).

Majority of glass packages (99%) were consumer packages. Those include the upscaled estimate on consumer packages reported by RINKI, beverage package volume reported by Palpa, online sales from abroad and private imports of alcohol. Business packages (1%) include the upscaled estimate on business packages reported to RINKI.

Altogether the volume of glass packaging on the market was 96 000 tonnes. The corresponding number in the producer responsibility statistics was 85 000 tonnes (Pirkanmaa ELY Centre). The amount of packaging released on the market from outside the reported numbers was estimated to be 9 000 tonnes (9%) in this study. The amount of glass packaging released on the market is presented in Table 51.

Table 51. Glass packaging released on the market in Finland in 2020 (in tonnes).

Glass packaging	amount/ t
packages released on the market	92 000
- reported volumes	- 88 000
- free-riders and <1 M € companies	- 4 000
online sales from abroad	322
private imports of alcohol	5 000
total	**96 000**

4.4.5.1.3 Distribution of packaging waste to separate collection and municipal solid waste (primary waste)

A return system for glass bottles has been in place since the 1950's and bottles are returned almost one hundred percent (Palpa 2022). The separately collected amount of glass packaging waste in 2020 was 80 000 tonnes (producer responsibility). The amount is similar to data from Statistics Finland.

The amount of glass packaging in the mixed MSW was 30 000 tonnes in 2020. The percentage of glass packaging in MSW is estimated to be 1,9%. 11 000 tonnes of the mixed MSW are estimated to be generated by service industries (35%) and 20 000 tonnes by households

(65%). Glass packaging in the MSW was calculated based on the national estimates on the composition of MSW and adjusted with a correction factor for dirt (RFV 2005). The amount of glass packaging waste is presented in Table 52.

Table 52. Glass packaging waste in Finland in 2020 (in tonnes).

Glass packaging waste	amount/ t
separate collection	80 000
mixed MSW	30 000
- service industry (35%)	- 11 000
- households (65%)	- 20 000
total	**110 000**

4.4.5.1.4 Packaging waste received and processed in secondary material production

In 2016 from the amount of recycled glass packaging waste 78% was from beverage packaging deposit scheme and 22% was other type of glass packaging waste. The data of recycled glass packaging is based on weighing's from treatment facilities prior to treatment. If the weighing was done after the processing, the amount of recycled would need to be reduced by approx. 1% in regards of deposit -based beverage glass packaging and 1-5% from other type of glass packaging waste (Statistics Finland 2019).

The producer responsibility statistics were in 2012 lacking data on glass packaging waste utilized by municipalities in civil engineering. The estimated amount was 5,000-7,000 tonnes. The estimate was based on published data by municipalities and on the data from SKY on the amount of applied recovery aid for glass packaging use in civil engineering. The utilization of glass in civil engineering is not considered recycling. (Jokinen et al. 2015)

In Finland, recycled glass is used to make glass wool and foam. Glass can be recycled indefinitely, for example to make new packaging, without compromising its quality or purity (Rinki 2022).

According to Statistics Finland the amount of glass recycled in 2020 was 80 000 tonnes, 722 tonnes were disposed. This includes also other products than packaging. The amount of packaging recycled in 2020 according to the producer responsibility was 77 000 tonnes, 444 tonnes were utilized in earthworks. The recycling percentage in 2020 was 80% (calculated from the amount of packages released on the market and the amount recycled). The amount of glass packaging waste recycled is presented in Table 53.

Table 53. Glass packaging waste recycled and used in land construction in 2020 in tonnes (producer responsibility statistics).

Glass packaging waste	amount/ t
recycled	77 000
earthworks	444
total packaging waste (recycled + earthworks)	**78 000**

4.4.5.1.5 Summary

The summary of glass packaging flow in tonnes during different life cycle stages is presented below in Table 54.

Table 54. Glass packaging flow in different life cycle stages in Finland in 2020 (in tonnes).

life cycle stages	glass packaging/t
Import-export	43 000
Release on the market	96 000
Separate collection	80 000
Packages in mixed MSW	30 000
Waste generation estimate (MSW+ producer resp.)	110 000
Received for secondary material production	77 000
Utilized in earthworks (producer resp.)	444

4.5 **Discussion and concluding remarks**

Considering the individual sets of data covering the different life cycle stages of packaging, packaging material volumes released on the market were the most comprehensive and disaggregated data. That said, these figures can be regarded as an anchor or baseline against which the rest of the data can be compared to. Packaging materials released on the market are reported for 164 industries or grouped industries and the data are divided into consumer packages and business packages allowing further analysis on the fate of these packaging materials in terms of waste generation. Consumer packages can be largely allocated to households while business packages enter other industries.

We made preliminary testing how the packaging waste generation across different industries could be estimated by using input-output table. In this approach, packaging material intensity is first calculated for each industry on the supply side and packaging waste generation on a specific industry is then calculated by multiplying the use of intermediary products with the above intensities. This approach seemed feasible as such but needs further elaboration and testing. Overall, the total packaging waste generation volume is by and large identical to the volume of packages released on the market. However, the following streams also need to be addressed when the total packaging waste volumes are considered: First, packages and packaging materials bought by households. These items are regarded as manufactured packages but are not defined as packages released on the market and falling under producer responsibility legislation. Therefore, such packages should not be placed in separate collection of packaging waste financed by producer responsibility. In reality, households willing to sort their waste and return it to separate collection systems likely return packages and packaging materials they have purchased into the separate collection bins as well. Consequently, this flow is likely included in the sum of collected waste but currently not counted in the packaging materials against which the recycling rate is calculated. Inclusion of this stream in the packaging materials would slightly lower the present recycling rate. How much the impact would be, we didn't quantify in the present study.

Data on packages imported by tourists (households) and via households' internet purchases from abroad were estimated by utilizing several different data sources from national statistics to previous studies and reports. The average estimated value of goods purchased online was used in this study and the share of foreign trade was based on survey studies aimed at customers. These surveys also provide information on which products have been bought from abroad, but these percentages cannot be directly linked to the value of the products. For this reason, the amount of packages were estimated based on producer responsibility data. In the future, the estimations could be verified by using tracking data e.g. from the post office on packages arriving to Finland via online shopping from abroad. Due to a lack of data, packages entering Finland with private imports from abroad do not concern products other than alcohol and the estimate made in this study may presumable be thus an underestimate.

One of the key challenges in the estimation of packaging waste has been the quantity of packages that are in the mixed municipal solid waste (MSW). By using the data collected in this study, packaging material from separate collection could be deduced from the (consumer) packaging materials released on the market (including households' imports and on-line internet purchased from abroad). This is the maximum volume of (consumer) packages that could enter the mixed MSW. Table 55 summarizes the different sets of data collected in the present study. Based on this comparison, the estimates of the volume of packages in mixed MSW seems too high (as indicated in parentheses) for paper and cardboard (31 000 tn) and glass (16 000 tn) packages. Due to the availability of data, the estimate of the composition of mixed MSW was based on the composition of household waste (KIVO). However, the composition of mixed MSW from other sources, such as administration, services and business can vary greatly from this. The estimate on the amount of packaging among the mixed MSW is also affected by correction factors used for dirt. According to an earlier study conducted in Sweden in 2005, the packaging among the mixed waste was found to be dirtier than in the more recent study from 2016. In this study, the estimate from 2005 was used, because with the correction factors of 2016, the amount of packaging waste among mixed MSW would have been unrealistically high in comparison to the amount of packages released on the market (as indicated in parentheses); paper and cardboard (99 000 tn), plastic (158 000 tn), metal (19 000 tn) and glass (25 000 tn). A similar study has not yet been conducted in Finland, and there could be a demand for it to refine the assessment.

Table 55. The packaging material flows in different life cycle stages in Finland in 2020 (in tonnes) for paper and cardboard (fibre), plastic, metal, wood and glass packages. For packages in mixed municipal waste (MSW), two values are given. First value is calculated on the basis of MSW composition and dirt factors and the value in parentheses is calculated as the indicative maximum volume in MSW as a remainder from "release on the market" minus "packages in separate collection".

Life cycle stages	Fibre	Plastic	Metal	Wood	Glass
Manufacture +import-export	238 000	134 000	35 000	164 00	43 000
Release on the market	367 000	164 000	57 000	289 000	96 000
Separate collection	336 000	62 000	44 000	78 000	80 000
Packages in mixed MSW	75 000 (31 000)	107 000 (102 000)	14 000 (13 000)	-	30 000 (16 000)
Received for secondary material production	332 000	41 000	44 000	78 000	77 000
Energy recovery+ other (producer resp.)	6 000	115 000		223 000	444

Overall, the method developed in the present study would make a solid, transparent and reproducible method for the compilation of accurate and complete national packaging accounts. The method addresses both reported and unreported packaging volumes and helps to identify the relevance of unreported – referring to free-riders and companies with turnover below 1 million euros – packaging. When operationalized, some issues would need to be resolved. First, it would be beneficial and significantly reduce need for manual labour if the companies reported their data independently. In the current practice, some consolidated companies or alike report packaging materials released on the market on behalf of their sister companies. This is problematic when the sister companies' NACE affiliation is different from that of the consolidated company. In such cases the primary data is available by a sister company level and changes would be needed in the reporting phase only meaning some additional work for the reporting company, which could still be the consolidated company. Second, the NACE affiliation and turnover of each reporting company would need to be correct so that the representativeness of the sample (by industry) and hence the upscaling accounting for the free-riders and small enterprises would be calculated correctly. To feed these data into the reporting system to RINKI would likely require some additional work from the reporting company and might not result in fully correct reporting results in this regard. An alternative to this would be an automatic or manual utilization of turnover and NACE affiliation data already collected by Statistics Finland (in regional entrepreneurial activities). If done manually, the work is laborious. In any case, the compilation of these accounts would need to be operationalized by officials having an access to the necessary datasets.

The varying definitions for "packaging" causes some problems in the accounting. Packages in PRODCOM classification are not identical to packages meant by packaging legislation. In the accounting this becomes apparent from the considerable difference in the volumes of manufactured packages versus packages released on the market, the latter being a much higher volume. This also complicates the calculation of recycling rates. Let us exemplify this problem.

Plastic films of paper sheets can be used as packaging materials and in this purpose they are regarded as packaging. However, these products have several other uses. Some of the paper sheets used as packages may be returned to separate collection of paper (and not cardboard) meaning that this material is recycled (or at least collected for recycling) but not included in the separate collection of packages. While this stream might not be that decisive for the overall recycling rate calculation, the challenge is that the current data give little opportunities for the quantification of this stream because the manufacturing volumes for such paper products used for packaging are not known and cannot be directly obtained from industrial output or similar statistics. In any case, this waste stream being excluded from the recycled volumes lowers the recycling rate.

Survey to the packaging manufacturers yielded highly representative results with the exception of wood packages. While these data cannot be used for the compilation of packaging accounts for the reasons specified above, they are most useful for the estimation of the recyclability of the different packaging materials. This is particularly relevant in the case of plastic packaging the current recycling of which relies heavily on mechanical recycling not well suited of multimaterial plastic packaging.

In the course of the compilation, some additional data gaps and elements of uncertainty were identified: The statistics lack data also regarding the packaging discarded for quality reasons at the time of use and filling. As the waste is generated prior to the release on the market the waste is pre-consumer. The data gap could be filled by obtaining data directly from companies. Furthermore, there were 142 industries that had purchased packaging materials according to the regional entrepreneurial statistics' microdata and that were completely missing from the RINKI data. These 142 industries' packaging purchases represented 5% of all packaging purchases and should be added on top of the accounts of packages released on the market. However, as there is no information as to which material this packaging was, an addition was not made at this point. Also, small shipments inside EU do not require a customs declaration and the existing data on imports and exports of plastic waste do not separate packaging from other shipments of paper and cardboard waste. Also, the amount of paper and cardboard packaging waste in littering and burned in household fireplaces/saunas are missing from the statistics, but these amounts can be estimated to be small.

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5 List of supplementary materials

Supplementary material 1. 2018 Resource Rent calculation by fleet by species

Supplementary material 2. Aquatic ecosystem account_supply and use account, asset account, and NPV calculation

Supplementary material 3. Pirkkala forest and urban greenspace ecosystem extent account and supply and use account of recreational and educational ecosystem services for year 2022.

Supplementary material 4. Tampere ecosystem account for year 2018.

Supplementary material 5. Helsinki urban greenspace ecosystem account for year 2022.

Supplementary material 6. Survey form of educational visit to nature in Pirkkala.

Supplementary material 7. Survey form of recreational use of green and water areas in Pirkkala.

Supplementary material 8. Individual- and aggregated industries, for which industry-specific package flow accounts were compiled.

Supplementary material 9. NACE-codes for the industries, for which package accounts are reported and the actual mass of packaging materials put on the Finnish market by these industries in 2020