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RESEARCH

Economic valuation of the ecosystem services provided by Pāmu Landcorp farms

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Abstract: Consideration of the value provided by ecosystem services is becoming increasingly integrated into decision-making processes including, for instance, both the New Zealand Government's recently adopted Living Standards Framework and the proposed Genuine Progress Indicator. However, to encourage wider uptake of the concept, there is a need to value and assess the provision of ecosystem services at scales relevant to local landowners and land managers in New Zealand. The current study was initiated by Pāmu Landcorp Farming and addresses this issue by assessing the economic value provided by ecosystem services across 126 of the Pāmu Landcorp farm units. These comprise 190 388 hectares of land. Properties include 'productive' operational units (e.g. pastoral, horticultural, and exotic forestry land) and 'non-productive' areas (e.g. indigenous scrub, forest, and wetlands, including land retired from production), both categories of which provide an array of important ecosystem services which have not been systematically valued to date. Individual Pāmu Landcorp land parcels on each farm were assigned a broader ecosystem classification based on the framework developed by Patterson and Cole (2013). Ecosystems were scaled to reflect current spatial extent using the New Zealand Land Cover Database V4.1 (2015), and ecosystem service values adjusted to net present value and divided by area to provide results in 2019 NZD \$ hectare^{-1} year^{-1}. Findings reveal that while Pāmu Landcorp's 'non-productive' land comprises only 16.2% of total area, the net value of ecosystem services provided per hectare per year are 29.2% higher than productive land (\$1388 and \$1961 for 'productive' and 'non-productive' land, respectively). Additionally, while wetlands comprise only 0.8% of total land area, under this analysis they provide an estimated 8% of net total economic value, reflective of the higher values attributed to this ecosystem (\$14 208 ha^{-1} yr^{-1}). The valuation framework developed in the current study has the potential for wider uptake by landowners, land managers, iwi, the New Zealand farming industry, and regional and district councils, and helps to inform decision-making when considering the costs and benefits of activities which affect the provision of ecosystem services.

Keywords: economic valuation, ecosystem services, land management and decision making, Pāmu Landcorp farms, productive and non-productive land

Introduction

Ecosystem services are defined as the benefits people obtain from ecosystems (Millennium Ecosystem Assessment 2005). Such benefits can be quantified and valued, including through methods which monetarise services. The fundamental importance of ecosystem services for human wellbeing is now a well-established concept (Gardiner & Huser 2017), and ecosystem services are becoming increasingly integrated into decision-making processes. For example, the New Zealand Government has recently adopted the Living Standards Framework to help guide decision making through assessing impacts on intergenerational societal wellbeing (New Zealand Treasury 2018). It marks a shift away from purely economic metrics such as Gross Domestic Product (GDP) as the sole indicator of progress, and incorporates the impacts that decisions have on the provision of ecosystem services (or natural capital) as one of the four pillars underpinning the framework. These decisions occur at multiple levels; from day-to-day considerations influencing specific land use practices, to decision-making relating to permitting and development, through to the policy level, and all have impacts on natural capital stocks and the provision of ecosystem services. Additionally, momentum is growing to adopt more holistic measures of wellbeing such as the Genuine Progress Indicator as a means to capture the costs and benefits associated with economic activity, such as the loss of soil ecosystem services or infilling of estuaries and harbours through sedimentation which are not tracked by GDP (Patterson et al. 2019). However, one important remaining challenge is to distil ecosystem services valuations to local and regional scales to ensure relevance and encourage application of the concept in practice.

In this regard, the current study was initiated by Pāmu Landcorp Farming with the aim of assessing the potential economic value generated by ecosystem services across most of the company's landholdings. This encompasses approximately

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190 388 hectares of owned and leased land across 126 farm properties throughout Aotearoa/New Zealand. Properties comprise both 'productive' operational units which provide direct economic returns (e.g. pastoral and horticultural land as well as exotic forest), and 'non-productive' areas such as indigenous scrub, forest, and wetlands, including land retired from production. Both productive and non-productive lands provide an array of important ecosystem services that have not been categorically valued to date.

Findings from this analysis are intended to provide guidance to assist with farm management and decision-making. They hold relevance not just for Pāmu Landcorp farms but also for New Zealand's wider primary production industries and land managers. For instance, results will assist with reporting under Pāmu Landcorp's national-level Land and Environment Plan, but may also help other landowners and farmers in providing an economic justification for the retirement of productive or marginally productive land. Results also provide incentives to capitalise on emerging domestic and international markets such as the development of payment for ecosystems service (PES) schemes, e.g. forest carbon projects.

Methods

Ecosystem classification framework and economic valuation

Ecosystem services are typically classified under five broad categories for valuation: supporting, regulating, provisioning, cultural, and passive (MEA 2005). Examples of the types of ecosystem services provided under each of these categories are outlined in Table 1.

The current study utilises an ecosystem service valuation framework for New Zealand developed by Patterson and Cole (2013) which builds on the MEA (2005) classification system. These authors provide a comprehensive effort to estimate the total economic value (TEV) derived from the country's land-based ecosystems and their services (Patterson & Cole 2013) per annum. Given the paucity of explicit ecosystem service valuation studies undertaken in New Zealand, Patterson and Cole (2013) primarily use a method that relies on 'benefit transfer valuation'. This approach utilises information from studies undertaken in other countries and transfers these, as far as practicable, to the New Zealand context.

Land area in Patterson and Cole (2013) is assigned to 12 standard ecosystems based on amalgamations of the 47 vegetative classes from the original Vegetative Cover Map of New Zealand (Newsome 1987). However, the proportions of each ecosystem have changed markedly since this publication more than 30 years ago, with the area of 'exotic forest' for instance increasing by 169% (1 212 000 hectares in Newsome (1987) to 2 045 226 as LCDB V4.1 (2015)) which accordingly changes valuation on a per hectare per year basis. In the current study, we used land areas for each standard ecosystem as of 2012 reported in the most current version of the New Zealand Land Cover Database (LCDB V4.1 2015). The exception is for 'wetlands', with data based on a more up-to-date assessment of both the spatial extent and ecosystem service value by Patterson et al. (2019). TEV is then divided by land area (hectares) for each ecosystem to provide a valuation of each standard ecosystem per hectare per year (Table 2).

Patterson and Cole (2013) used the New Zealand dollar value in 2012. In Table 2, this is adjusted to reflect net present value (NPV) as of 2019 using an inflation rate reflective of the country's economic growth of 8.1% (Reserve Bank of New Zealand 2019). The area of each land parcel was then multiplied by the ecosystem service values of its corresponding ecosystem to provide values in 2019 NZD \$ ha^{-1} year^{-1}. Results are also presented as both gross and net values. Gross values are the sum of all supporting, regulating, provisioning, cultural, and passive values, whereas net value excludes supporting values due to a propensity for 'double counting' of values already encapsulated under the regulating and provisioning categories. Due to this discrepancy, net values are discussed in the Results and Discussion sections below.

The New Zealand LCDB V4.1 (2015) was then used as a basis to assign different land use categories across the 836 discrete land parcel unit descriptors that comprise Pāmu Landcorp's farms used in this analysis. Each of the 34 reported LCDB categories were then assigned to a broader classification (Appendix S1 in Supplementary Materials) based on the standard ecosystem types reported in Patterson and Cole (2013). However, we also divided Patterson and Cole's (2013) original 'forest' classification into 'exotic forestry' and 'indigenous forest' to more accurately reflect the differing ecosystem service values of each. Exotic forests planted for timber production have a directly quantifiable economic market value represented under the 'raw materials' sub-category of 'provisioning' ecosystem services from Patterson and Cole (2013). This service in general does not apply for indigenous forests in Aotearoa/New Zealand, and in the current study we assume that all other services for 'forests' (e.g. climate regulation and recreation) in Patterson and Cole (2013) are attributed to indigenous forests only. Note also that there

Table 1. Examples of ecosystem services; adapted from Patterson and Cole (2013) and the MEA (2005).

Category	Description	Types of Ecosystem Services
Supporting	Processes which support regulating and provisioning services.	Nutrient cycling, soil formation, provision of habitat.
Regulating	Regulation of biophysical and ecological processes.	Climate regulation, flood control, control of pest species, water quality.
Provisioning	Direct provision of goods and services.	Food, water, timber, fibre, freshwater.
Cultural	Maintenance of human health and wellbeing.	Education, scientific knowledge, cultural wellbeing.
Passive	Value not related to the actual use of ecosystems, which can be subdivided into option, bequest, and existence value components.	Willingness to pay for the preservation of an ecosystem.

Table 2. Land use classification system adapted from Patterson and Cole (2013) and Newsome (1987) used to assign ecosystem service values to Pāmu Landcorp farms. Land areas for each ecosystem classification are sourced from the NZ LCDB V4.1 (2015) and, for wetlands, Patterson et al. (2019). Values are presented in 2019 \$ ha^{-1} yr^{-1} rounded to the nearest whole dollar. Economic values for wetlands are sourced from Patterson et al. (2019) and converted to 2019 \$ ha^{-1} yr^{-1} using an inflation rate of 5.5% (Reserve Bank 2019). All other values are converted from Patterson and Cole (2013). Passive Value is reported as being not applicable (N/A) where it was not estimated by Patterson and Cole (2013).

Ecosystem Classification	NZ Land Area (ha)	Supporting Value	Regulating Value	Provisioning and Cultural Value	Passive Value	Gross Value	Net Value
1. Horticulture and cropping	473 348	$53	$7	$5173	N/A	$5232	$5180
2. Agriculture	10 624 386	$789	$340	$923	N/A	$2052	$1264
3. Exotic forestry	2 045 226	N/A	N/A	$3691	N/A	$3691	$3691
4. Intermediate agric-scrub	2 933 569	$699	$601	$410	N/A	$1709	$1010
5. Scrub	1 678 044	$392	$342	$3	N/A	$738	$345
6. Forest	7 061 198	$535	$468	$99	N/A	$1102	$567
7. Wetlands	249 579	$14 210	$9676	$4531	N/A	$28 417	$14 208
8. Estuaries	114 672	$9672	$2960	$1028	$1989	$15 649	$5977
9. Mangroves	28 097	$0	$3963	$0	$1577	$5540	$5540
10. Lakes	359 537	$5217	$1636	$14 044	$2661	$23 557	$18 341
11. Rivers	82 782	$16 832	$5276	$45 313	$18 726	$86 146	$69 314

was no Pāmu Landcorp land assigned as 'intermediate agric-forest' or 'forest-scrub', which are ecosystem categories in Patterson and Cole (2013). Additionally, Molesworth Station, the country's largest farm at 152 966 hectares, was excluded from this analysis. Inclusion of Molesworth Station would have effectively almost doubled the area of farmed land (70 049 hectares of productive land or 44.3% of total productive area across all of Pāmu Landcorp lands) yet the station carries less than 1% of overall stock (G Williams, Pāmu Landcorp, pers. comm.). To put this in perspective, the next largest Pāmu Landcorp farm is Waipori Station at 12 556 hectares and including Molesworth Station would have disproportionately skewed the results. The remaining 126 Pāmu Landcorp farms can be considered a better microcosm of New Zealand's farming industry in general (G Williams, Pāmu Landcorp, pers. comm.).

Limitations

The desktop valuation of ecosystem services presented in the current study is necessarily high-level and broad in scope, and this imposes limitations for interpretability. Firstly, the 'benefit transfer' methodology means that some ecosystem services and values attributed to particular ecosystems from overseas studies may be under- or over-valued, and results should be interpreted as indicative only. However, indicative results are still useful to tease out broader questions such as which ecosystems provide relatively more value and which services are most important. Secondly, the scope of the study is necessarily restricted to a monetary assessment of the economic values provided by ecosystems on Pāmu Landcorp farms. While non-monetary valuation would enable a more complete understanding of the values placed on ecosystems and complement monetary valuation, it also requires methodological approaches (e.g. qualitative preference assessments and surveys of landholders) that are outside the scope of research. Patterson and Cole (2013) also combined 'provisioning' and 'cultural use' ecosystem service values in their TEV assessment, given that both categories have a direct, quantifiable and tangible benefit to humans. For consistency, we used the framework developed by Patterson and Cole (2013) whilst noting that at a more detailed, site-specific level it would be more beneficial to explicitly separate the values attributed under each category. Additionally, the valuation of ecosystem services for 'unproductive' lands is limited by the fact that often it does not reflect the value that these services can actually generate as tradeable market commodities. Rather, it is an assessment of (mostly) intangible societal values for healthy, unimpacted ecosystems that cannot be fully monetarised under, for instance, current PES trading systems. Finally, while Paterson and Cole (2013) provide the most comprehensive assessment of ecosystem services undertaken to date for New Zealand's terrestrial landmass, as more research is undertaken and published the valuation framework will change accordingly. For instance, Patterson et al. (2019) have recently released a report addressing the use and application of a Genuine Progress Indicator for Aotearoa/New Zealand which includes more recent estimates of the value of services provided by some ecosystems. While we have incorporated the values reported for 'wetlands' from Patterson et al. (2019) in this analysis, further research into other ecosystems will, in turn, change the values attributed.

Results

The analysis of ecosystem service valuations across Pāmu Landcorp's farm holdings shows that the large area of agricultural land under production (157 316 ha of mostly high and low producing exotic grasslands) correlates to the highest estimated net annual returns for any ecosystem overall (\$198 800 176 yr^{-1}; Table 3). Exotic forestry provides the next largest returns with an estimated \$34 442 887 yr^{-1}, or 12% of the net value provided by all ecosystems (Fig. 1). When land use categories are collectively grouped into either non-productive or productive land, while Pāmu Landcorp's non-productive land contributes only 16.2% of total area, the net value of ecosystem services provided per hectare per year are 29.2% higher than productive land (\$1388 and \$1961 ha^{-1} yr^{-1} for productive and non-productive land, respectively).

When ecosystem services are quantified as a proportion of total area, the disproportionate value attributed to freshwater wetlands stands out distinctly (Fig. 1). Whilst comprising only

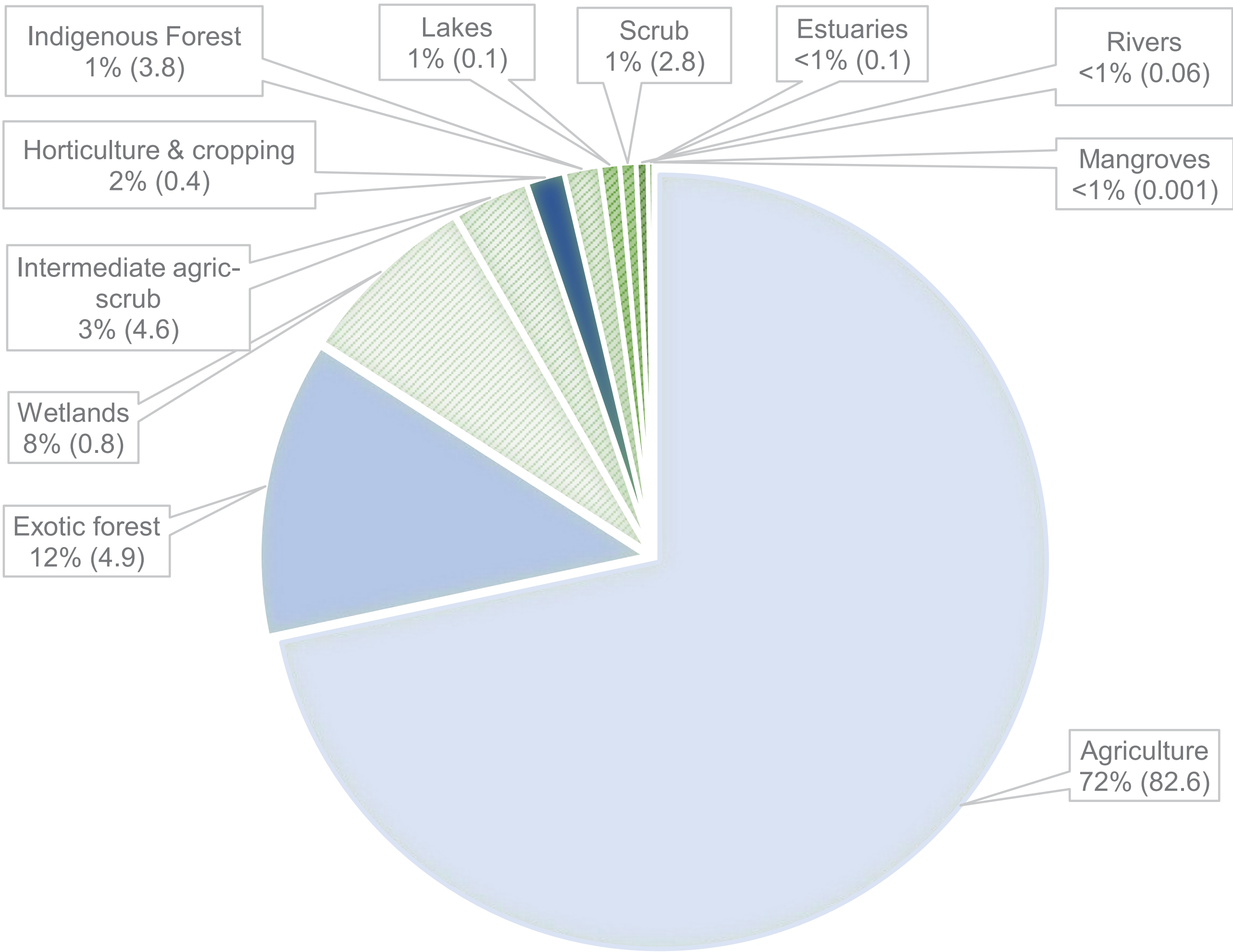

Figure 1. Proportional net economic values of services provided by each ecosystem type represented on Pāmu Landcorp farms, with proportional areas in parentheses. Productive lands are shaded in blue and unproductive in green.

Table 3. Estimated ecosystem service values by land use classification across Pāmu Landcorp farm holdings (excluding Molesworth Station). Values are presented in 2019 $ per year rounded to the nearest whole dollar. Note total area excludes 279.1 ha of non-assigned land such as landslides, buildings, infrastructure. Passive Value is scored as not being available (N/A) where it was not estimated by Patterson and Cole (2013).

Land Classification	Total Area (ha) of Pāmu Landcorp Farms	% of Total Area*	Supporting Value	Regulating Value	Provisioning and Cultural Value	Passive Value	Gross Value	Net Value
1. Horticulture and cropping	841.9	0.4	$44 224	$5768	$4 355 111	N/A	$4 405 103	$4 360 879
2. Agriculture	157 316.2	82.6	$124 066 036	$53 541 593	$145 258 583	N/A	$322 866 212	$198 800 176
3. Exotic forestry	9332.0	4.9	N/A	N/A	$34 442 886	N/A	$34 442 886	$34 442 886
4. Intermediate agric-scrub	8667.2	4.6	$6 058 613	$5 205 872	$3 551 491	N/A	$14 815 976	$8 757 363
5. Scrub	5352.0	2.8	$2 099 704	$1 830 777	$17 239	N/A	$3 947 720	$1 848 016
6. Forest	7155.2	3.8	$3 829 491	$3 348 614	$709 814	N/A	$7 887 919	$4 058 428
7. Wetlands	1473.4	0.8	$20 937 285	$14 257 686	$6 676 490	N/A	$41 871 461	$20 934 176
8. Estuaries	107.3	0.1	$1 038 071	$317 694	$110 282	$213 482	$1 679 530	$641 459
9. Mangroves	1.4	0.0	N/A	$5566	N/A	$2215	$7 781	$7781
10. Lakes	122.1	0.1	$637 141	$199 772	$1 715 323	$324 997	$2 877 233	$2 240 092
11. Rivers	19.3	0.0	$325 234	$101 935	$875 533	$361 820	$1 664 523	$1 339 288
'Productive' land (1-3)	167 490.1	88.0	$124 110 260	$53 547 362	$178 916 354	N/A	$356 573 976	$232 463 716
'Unproductive' land (4-11)	22 898.0	12.0	$34 925 540	$25 267 916	$13 656 172	$902 515	$74 752 143	$44 894 167
Total	**190 388.1**	**100.0**	**$159 035 800**	**$78 815 278**	**$192 572 527**	**$902 515**	**$431 326 119**	**$277 357 883**

0.8% of total land area, under this analysis they provide an estimated 8% of net TEV, reflecting the higher valuation of services provided by this ecosystem ($14 208 ha^{-1} yr^{-1}). For instance, Eweburn Station, Centre Hill Station, and Sweetwater Farm have 313.9, 122, and 190.2 ha of freshwater wetlands, respectively, which are estimated to contribute a combined net value worth $8 895 629 yr^{-1} representing 43% of TEV from these farms Intermediate agric-scrub, horticulture and cropping, and indigenous forests are the next highest contributors across Pāmu Landcorp farms with 3%, 2% and 1% of TEV, respectively.

Discussion

The current study indicates that while Pāmu Landcorp's unproductive lands (primarily) do not exhibit directly quantifiable, fungible economic returns as the market-based commodities generated on productive lands do, the services provided are still extremely valuable within a societal context. Capitalising on these services and entrenching the values provided by non-productive lands as integral components within land use decision making requires further elucidation at a site-specific level. This includes assessments of the relative quality of ecosystems, as well as the potential to utilise market-based incentives.

Results should be treated as indicative only and could be improved through a more detailed, site-specific analysis across selected farms which would considerably improve and update our understanding of ecosystem service valuation in New Zealand. This would enable not only quantification of both the actual values generated from productive lands – a very useful comparison to make against the generic desktop values reported here – but also a systematic assessment of the specific ecosystem services values generated by non-productive lands. For instance, not only does Eweburn Station encompass a large area of freshwater wetlands, it also has a large area (424.6 ha) of mānuka (*Leptospermum scoparium*) and kānuka (*Kunzea ericoides*) which is classified as 'scrub' in this assessment, with a moderate net TEV of $345 ha^{-1} yr^{-1} (Table 4). This ecosystem is likely to have a greater value than estimates in the current study given the extremely high market value for mānuka honey and essential oils. While the Te Anau basin within which Eweburn Station is located is currently not recognised for producing mānuka honey or essential oils, in 2017 these commodities were estimated to contribute $280 million to New Zealand's economy (Gines et al. 2017) with the median income for honey alone estimated at $1750 ha^{-1} yr^{-1} (McPherson 2016). Mānuka is also increasingly recognised for its ability to absorb and regulate nitrates, with studies reporting that sewage sludge leachate in soil beneath mānuka was only one third of that reported from pasture and, when urea is applied, can be 25 times less than leachate from radiata pine (Esperschuetz et al. 2017). These regulating services have correspondingly high societal values and should be used in guiding land management decisions, such as prioritising of activities which protect or enhance high value ecosystems. For example, existing riparian margins could be supplemented through plantations of mānuka/kānuka, while farm effluent could be applied to habitat away from stream margins (instead of pasture) to help maintain the high values attributed to receiving bodies such as wetlands, rivers, and lakes.

Another important aspect that requires consideration when interpreting results is the relative quality and condition of ecosystems. The framework used here is based on a broad axiom whereby each ecosystem provides a uniform value based on the service provided by healthy and intact habitats. In reality, at the individual farm unit scale, ecosystems are

Table 4. Estimated ecosystem service values by land use classification for Eweburn Station. Values are presented in 2019 NZD$ per year rounded to the nearest whole dollar.

LCDB Classification	Assigned Land Classification	Area (ha)	Supporting Value	Regulating Value	Provisioning and Cultural Value	Passive Value	Gross Value	Net Value
Broadleaved Indigenous Hardwoods	6. Forest	27.8	$14 880	$13 011	$2758	N/A	$30 650	$15 770
Exotic Forest	3. Forest	N/A	N/A	N/A	$172 709	N/A	$172 709	$172 709
Fernland	5. Scrub	20.4	$7 896	$6963	$66	N/A	$15 015	$7029
Gorse and/or Broom	4. Intermediate agric-scrub	1.8	$1272	$1093	$746	N/A	$3111	$1839
Herbaceous Freshwater Vegetation	7. Wetlands	313.9	$4 460 307	$3 037 152	$1 422 213	N/A	$8 919 673	$4 459 366
High Producing Exotic Grassland	2. Agriculture	2683	$2 115 942	$913 150	$2 477 381	N/A	$5 506 473	$3 390 531
Indigenous Forest	6. Forest	23.4	$12 527	$10 954	$2322	N/A	$25 803	$13 276
Lake or Pond	10. Lakes	4.2	$21 687	$6800	$58 387	$11 062	$97 937	$76 249
Low Producing Grassland	2. Agriculture	331.9	$261 715	$112 945	$306 420	N/A	$681 080	$419 365
Mānuka and/or Kānuka	5. Scrub	424.6	$166 571	$145 236	$1368	N/A	$313 175	$146,604
Matagouri or Grey Scrub	4. Intermediate agric-scrub	0.2	$164	$141	$96	N/A	$402	$238
Surface Mine or Dump	0. Not classified	0.7	N/A	N/A	N/A	N/A	N/A	N/A
Productive Land	12 (1–3)	3014.9	$2 377 657	$1 026 095	$2 956 510	$0	$6 360 263	$3 982 605
Unproductive Land	13 (4–11)	863.0	$4 685 395	$3 221 352	$1 487 956	$11 062	$9 504 765	$4 720 370
Total		**3877.9**	**$7 063 053**	**$4 247 447**	**$4 444 466**	**$11 062**	**$15 766 028**	**$8 702 975**

likely to display variability in quality which will, in turn, affect both the provision and subsequent relative valuation of ecosystem services. A small area of disjointed wetlands low in species diversity and infested with exotic weeds, for instance, is unlikely to provide the same quality of ecosystem services as that of an intact, natural wetland. This reflects variability in key aspects such as the relative nutrient removal efficiency of wetlands – one of their primary ecosystem services – which varies depending on catchment position (Clarkson et al. 2013). Wetlands situated in lower elevation areas of catchments, with larger contributing areas, are more efficient at removing nitrogen, while wetlands in upper reaches, below small contributing areas where surface waters are generated, are most effective for removing phosphorus (Tomer et al. 2009). However, all wetlands help prevent nutrients from reaching toxic levels in groundwater used for drinking purposes and reduce the risk of eutrophication of aquatic ecosystems further downstream (Clarkson et al. 2013), which means that even heavily degraded wetlands and seepages provide high ecosystem service benefits in the form of nutrient attenuation and filtering of contaminants. Assigning a measure of relative quality, and therefore the degree to which ecosystem services are provided and valued ('quality hectares'), requires a systematic approach to assessment. In this regard, Wildland Consultants (2010) developed and applied a set of weighted criteria for ranking freshwater wetlands in Northland. The criteria developed included measures of representativeness, hydrological integrity, areal extent, the presence/absence of threatened species, and the relative dominance of indigenous species. Ausseil et al. (2011) developed a similar index of ecological integrity ranging from 1 (pristine) to 0 (complete loss of biodiversity and associated ecological function), while Clarkson et al. (2003 proposed a wetland condition index based on ecological indicators for use in state of the environment monitoring. Applying the Wildland Consultants (2010) criteria resulted in Taikirau Swamp emerging as the top-ranked wetland in Northland with a weighted score of 85.96. This large wetland complex (481.6 ha) supports a number of Threatened and At Risk birds (Miskelly et al. 2008) as well as regionally significant plant (De Lange et al. 2009) species, but it is also adversely impacted through water impoundment by willows and by weeds that envelop some wetland margins and therefore lowers the weighted score. In contrast, the lowest-ranked wetland in Northland was Frenchman's Bay which had a weighted score of only 37.44, largely resultant from a small area (0.7 ha) of low species diversity heavily impacted by domestic animal grazing (Wildland Consultants 2010). In this report it was assumed that healthy, unimpacted, high quality freshwater wetlands are valued at \$14 208 ha^{-1} yr^{-1} in terms of the provision of net ecosystem services. Under a 'quality hectares' approach, this would result in the valuation of Taikirau Swamp at \$12 213 ha^{-1} yer^{-1} with a total value multiplied by area of \$5 881 876 yr^{-1}. Frenchman's Bay wetland, however, is valued at just a fraction of this amount, at \$5319 ha^{-1} yr^{-1}, with an even lower total value of \$3724 yr^{-1} given its small size. Of importance, this is still \$2460 ha^{-1} yr^{-1} more than the estimated net value of agricultural land in the current assessment, which indicates that even small degraded wetlands dominated by exotic vegetation can provide highly important ecosystem services such as water quality regulation. If activities such as domestic stock exclusion fencing were to be undertaken at Frenchman's Bay wetland and this improved the quality of the ecosystem services provided (not necessarily the spatial extent) to the same condition as Taikirau Swamp, this could translate to net additional benefits (or gains) of \$4826 ha^{-1} yr^{-1}, i.e. from a current low value of \$3724 to \$8549 if the quality is improved to the same score as Taikirau Swamp.

The same 'quality hectares' valuation framework may also have relevance for productive lands. For example, one study assessed the economic value provided by uneroded, intact steep pasture lands grazed by sheep and cattle at \$3717 ha^{-1} yr^{-1}. This value dropped dramatically – by 65% to \$1301 – following a single shallow mass movement event which resulted in extensive topsoil loss (Dominati et al. 2014). Pāmu Landcorp currently employ a similar approach for assessment of the quality of some productive lands, where, for instance, the quality of grazing lands for sheep and beef production influences stocking densities while the quality of underlying soils guides decision making as to the types of horticultural produce grown. Development of a coordinated system across both productive and unproductive land units would enable a more robust estimate of both relative quality and how that translates into more accurate estimates of the provision and valuation of ecosystem services.

Furthermore, capitalising on the TEV of Pāmu Landcorp's unproductive land holdings could also include the improvement of habitats to potentially generate marketable PES commodities. Payment for ecosystem services schemes are broadly defined as market-based mechanisms that offer incentives to landowners in exchange for managing their land to provide some sort of ecological service (Farley & Costanza 2010) through, for instance, discouraging the over harvesting of resources or avoiding the destruction and degradation of habitat (Lau 2012). New Zealand has an established system of PES-related schemes which protect indigenous biodiversity on private land as shown by the numerous ratepayer funded and council-run biodiversity enhancement programmes that are common across the country as well as the high uptake of Queen Elizabeth II Trust Open Space Conservation Covenants (Maseky et al. 2019). However, the next step is to recognise biodiversity in farm planning as natural capital stocks that can be manipulated through management interventions to make a fundamental contribution to the provision of ecosystem services (Maseyk et al. 2019). This requires PES projects to deliver project-derived benefits over and above the business as usual scenario by passing a test of additionality. Additionality can be defined as whether a PES outcome (e.g. a reduction or removal in greenhouse gas emissions) would have occurred in the absence of a project (Bennett 2010). This is a crucial underpinning for PES projects but is not widely or clearly understood. For instance, demonstrating additionality might involve implementation of activities that restore and enhance wetland or mānuka habitats where specific project-derived ecosystem service benefits (e.g. water quality regulation, honey production, carbon sequestration) can be clearly distinguished from the business as usual scenario, quantified and marketed. Development of carbon offsets is currently the most accessible avenue to be explored for PES projects given that there are established compliance and voluntary markets. There is also a methodology for the creation of new wetlands under the Verified Carbon Standard (VCS 2014), and this could be of particular relevance for landholders in eastern regions of New Zealand where the development of small-scale dams for water retention is likely to be of increasing importance under the drier conditions driven by climate change (Ministry for the Environment 2018). Additionally, the ability to bundle discrete land units into a single project under the VCS reduces transaction costs (e.g. costs involved in third party verification), improves efficiency, and enables projects to be developed at larger spatial scales. If forest carbon projects can also demonstrate value-added biodiversity and social benefits it may attract a premium from potential buyers, particularly given the increasingly competitive voluntary market where companies seeking to offset emissions are driven by shareholder expectations to purchase products with benefits above and beyond a sole focus on carbon.

In conclusion, this study highlights the relevance and importance of including assessments of ecosystem services within the primary production sector. A more detailed elucidation of ecosystem services could be derived from a detailed site-specific study across a select number of Pāmu Landcorp farms comprising a variety of different ecosystem classifications. This should involve selection of farm units comprising a number of different high value ecosystem classifications, and should also involve an assessment of the relative quality of each ecosystem. Non-assessed farm units holding similar ecosystem classifications could also be included as a control and to compare results. Additionally, it would be worthwhile to explore the potential to develop PES projects on Pāmu Landcorp farm holdings with existing high value ecosystems. The valuation framework presented here has the potential for wider uptake by landowners, land managers, iwi, and regional and district councils, and should help to inform decision-making around the costs and benefits of activities which affect the provision of ecosystem services.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Ecosystem classifications based on Patterson and Cole (2013) assigned to LCDB V4.1 (2015) land use classes across Pāmu Landcorp farms.

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