He Tangata, He Taiao, He Ōhanga

a values-based biosecurity risk assessment framework for Aotearoa

NEW ZEALAND'S BIOLOGICAL HERITAGE

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National SCIENCE Challenges

# A review of environmental values for New Zealand biosecurity risk assessment

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19 November 2021

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New Zealand natural and modified landscapes

# Report information sheet

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| **Report title** | A review of environmental values for New Zealand biosecurity risk assessment |
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| **Client** | The National Science Challenge Biological Heritage - Strategic Outcome 3 (through AgResearch) |
| **Client contract number** | |
| **Scion QuikTrak number** | QT-9094 |
| **PAD output number** | 445 573 78 |
| **Signed off by** | Dr Steve A. Wakelin |
| **Date** | 19 November 2021 |
| **Confidentiality requirement** | Confidential (for client use only) |
| **Intellectual property** |  |
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Published by: Scion, Private Bag 3020, Rotorua 3046, New Zealand. www.scionresearch.com

# Executive summary

Biosecurity refers to keeping the environment free of unwanted organisms and controlling, managing or eradicating them should they arrive in the country. The New Zealand government allocated approximately $545 million for biosecurity in 2018/19, an amount considered low relative to the economic, ecological and social benefits of maintaining the environment's isolation from pests and diseases (Baisden, 2019; New Zealand Treasury, 2020). The Biological Heritage National Science Challenge Strategic Outcome 3 (BHNSC-SO3), "A values-based biosecurity risk assessment framework for Aotearoa" – is a four-year (2020 to 2024) multidisciplinary research programme, that aims to develop a holistic risk assessment framework that incorporates environmental, socio-cultural and Te Ao Māori values alongside economic values. This project is part of BHNSC-SO3 which focuses on a systematic literature review of studies that assessed the non-market environmental values provided by on-going and developing biosecurity programmes around the world and in New Zealand.

## The problem

Environmental values in biosecurity risk assessments remain poorly understood and are often ignored in decision making. This is despite significant evidence from the literature that environmental values can be more than double the financial value of the goods and services that an ecosystem provides (de Groot et al., 2012; Dhakal, Yao, Turner, & Barnard, 2012; R Yao, Palmer, Payn, Strang, & Maunder, 2021). Studies also show that biosecurity protection programmes are highly valued by society as they help protect important environmental amenities and conserve native species (Adams et al., 2020; Mazur, Bath, Curtotti, & Summerson, 2018; P. Tait & Rutherford, 2017). It is important to quantify these values robustly in order to accurately represent them in biosecurity risk assessments and decision making (Stoeckl, Dodd, & Kompas, 2018).

## This project

The objective of the project was to review and assess how environmental values (including the biotic and abiotic environments, ecosystem services, outdoor pursuits, tourism and genetic resources) may be captured and quantified in risk assessments. A systematic literature review was undertaken to identify and compile relevant studies that quantified the environmental impacts of biosecurity programmes and policies. To identify the studies, our team searched the international and New Zealand based literature and created a set of inclusion and exclusion criteria. The team agreed to use the natural capital and ecosystem services (NCES) framework, which can examine the connection between the environment and society. The NCES framework provides a lens to identify and examine key environmental related values provided by biosecurity protection initiatives to society (Bateman & Mace, 2020; TEEB, 2010).

## Key results

Biosecurity programmes are envisioned to protect, sustain and/or enhance the environment; such outcomes are valued by society. Non-market valuation techniques (described in the NCES framework) have been developed to measure those planned or observed environmental improvements.

Our literature search identified 775 studies which we examined using a set of inclusion and exclusion criteria which resulted in 59 relevant studies. We added 16 additional studies using pre-existing knowledge and experts in the field. A total of 75 relevant studies published between 2000 to 2021 were examined to identify and extract human-centred environmental values. The list of studies produced 729 estimated environmental values with a large majority (91%) consisting of non-market monetary value estimates. The monetary value estimates were standardised into 2021 New Zealand dollars.

Non-market values of biosecurity protection initiatives were estimated across various ecosystems including forest, marine, lake, agriculture, dryland and island. Value estimations were undertaken across different scales such as continent, country, region, city/town and catchment/watershed.

Quantification methods included non-market valuation techniques which aim to estimate how the change in the level of provision of environmental goods (e.g., recreation, conservation, ecological enhancement) can change a person's welfare or well-being. An example of a change in welfare value is the willingness of an individual to pay for a proposed biosecurity programme that would guarantee the prevention of a native species from becoming extinct.

## Implications of results for the client

The values compiled in this literature review provides an overview of the studies where the wider benefits of biosecurity interventions have been quantified and compared using indicators of ecosystem services. Those indicators may be used to identify what environmental factors and related items should be considered in a holistic value-based biosecurity risk assessment framework. Environmental values impacted by biosecurity have been found to be greater than financial values. Their protection would provide significant long-term benefits that would better justify the investments in biosecurity protection initiatives. Accounting for non-market environmental values in decision making would help sustain and enhance environmental quality, especially those that enhance human well-being.

However, there remains a severe lack of non-market valuation studies for biosecurity both globally and in New Zealand. In addition, non-market valuation of ecosystem services provided by biosecurity initiatives used different methods and, for each method, different approaches were employed resulting in different formats of reported values. There appears to be a lack of consultation with end users in the co-design of non-market valuation research.

The BHNSC-SO3 potentially provides an opportunity to undertake a holistic hybrid valuation approach as its current setup would facilitate interactions across disciplines enabling a more coordinated and transparent assessment of environmental values. This ensures that estimated values would supplement or complement other values that can be measured or qualitatively described using Te Ao Māori, social science, biophysical and economics lenses. As the BHNSC-SO3 team includes government agencies and industry representatives, there is potential to co-design an environmental valuation research framework which would enable the estimation of tailor-made non-market values specific to undertaking future biosecurity risk assessments. With this transdisciplinary research design, it is highly likely that environmental values would be robustly estimated and described, enabling their appropriate and transparent representation in biosecurity risk assessment initiatives and decision making.

## Further work

The non-market environmental values compiled in this project may be used to inform future cost benefit analyses, multi-criteria analysis and other tools used in the planning and implementation of future biosecurity programmes. From this literature review, gaps have been identified as discussed in the above paragraphs (i.e., lack of a co-designed, standardised non-market valuation research framework specific to a value-based biosecurity risk assessment), and BHNSC-SO3 provides an excellent research setting to fill these gaps where a co-designed transdisciplinary environmental valuation research would inform biosecurity decision making processes.

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# Introduction

Biosecurity refers to keeping the environment free of unwanted organisms and controlling, managing or eradicating them should they arrive in the country (Department of Conservation, undated). The New Zealand government allocated approximately $545 million for biosecurity in 2018/19 and this level of allocation has been considered low relative to the economic, ecological and social benefits provided by maintaining the environment's isolation from pests and diseases (Baisden, 2019; New Zealand Treasury, 2020). The New Zealand's Biosecurity 2025 Direct Statement document mentions that it is important for New Zealanders to protect the environment, economy, health, cultural and social values, indicating that all biosecurity protection initiatives benefit primary industries, tourism businesses and government agencies as well as local communities and New Zealanders in their everyday activities. However, non-market environmental values (e.g., recreation, environmental conservation and sustaining and enhancing the environment) in biosecurity risk assessments remain poorly understood and are often ignored in decision making. This is despite significant scientific evidence supporting that non-market environmental values can be more than double the financial value of the material benefits (e.g., timber) that an ecosystem provides (de Groot et al., 2012; Dhakal et al., 2012; R. Yao et al., 2021). Studies also show that biosecurity protection programmes within primary industries are highly valued by society more broadly, for instance, spill over benefits into protection of important native species and natural landscapes (Adams et al., 2020; Mazur et al., 2018; P. Tait & Rutherford, 2017). It is, therefore, important that these values be robustly quantified to facilitate their recognition and representation in biosecurity planning and decision making (Stoeckl et al., 2018).

The Biological Heritage National Science Challenge Strategic Outcome 3 (BHNSC-SO3) – titled "A values-based biosecurity risk assessment framework for Aotearoa" – is a four-year multidisciplinary research programme, that aims to develop a holistic risk assessment framework that incorporates environmental, socio-cultural and Te Ao Māori values alongside economic values. A small part of the BHNSC-SO3 is this sub-project which aims to review and assess how environmental values (including the biotic and abiotic environments, ecosystem services, outdoor pursuits, tourism and genetic resources) may be captured and quantified in risk assessments. A systematic international literature review was undertaken to identify and compile relevant studies that quantified the environmental impacts of biosecurity programmes and policies. To identify the studies, our team undertook literature search and creation of a set of inclusion and exclusion criteria. The team agreed to use the natural capital and ecosystem services framework (NCES), which captures the connection between the environment and society, and provides a lens to identify and examine the key environmental related values provided by biosecurity protection initiatives to society (Bateman & Mace, 2020; TEEB, 2010). With this NCES lens, the team went through the relevant published materials and compiled relevant information on values of ecosystem service benefits (and costs) given developing, on-going and completed biosecurity protection initiatives. Examples of these values include non-market monetary values of environmental protection and enhancement, increased number of visits to amenities, improved human health and well-being indicators).

The environmental values associated with biosecurity protection are generally not observed in market transactions (i.e., no market price) and this makes them difficult to quantify or estimate (Ian Bateman et al., 2011; Smith & Clough, 2000). To address this, environmental economists developed several non-market valuation (NMV) methods which have been continuously improved over the years and have been used to estimate the value of the goods and services provided by ecosystems (Cole, 2018; UKNEA, 2011). These methods have been used globally and in New Zealand to assess the impacts on environmental values of biosecurity initiatives and represent those values in risk assessments and decision-making processes (Kerr & Sharp, 2007; Stoeckl et al., 2018; P. Tait & Rutherford, 2017).

Our global literature search using Scopus identified 775 studies which we examined and filtered down to 59 studies using a set of inclusion and exclusion criteria. We also added 16 additional studies (which include those in the grey literature) using current knowledge and experts in the field. A total of 75 relevant studies published between 2000 and 2021 were examined to identify and extract human-centred environmental values. The list of studies produced 729 estimated environmental values, 91% of which were non-market monetary values.

Results of the literature review indicate that non-market values of biosecurity protection initiatives were estimated across various ecosystems such as forest, marine, freshwater, agriculture and other terrestrial ecosystems. Value estimation were also undertaken across different scales such as continent, country, region, city/town and catchment/watershed. Quantification methods include non-market valuation techniques which can estimate how the change in the level of provision of environmental goods (e.g., recreation, conservation, ecological enhancement) have changed welfare levels or affected human well-being. An example of a change in welfare value is the willingness of an individual to pay for a proposed biosecurity programme that would guarantee the prevention of a native species from becoming extinct.

The literature review also identified gaps in the area of valuing the flows of ecosystem goods and services from the environment, thus helping identify future research for the BHNSC-SO3 team which consists of researchers from different disciplines and end users from government agencies and industries. How to use these compiled environmental values, their limitations and some opportunities for collaborative work are described in the discussion section of this report.

# Background

New Zealand’s natural and modified ecosystems serve as a capital base providing goods and services that benefit the economy, environment and society. This flow of essential goods and services, that may have market and/or non-market values, are collectively called ecosystem services (ES). For example, the 5667 ha Whakarewarewa forest in Rotorua, New Zealand provides multiple ES such as carbon sequestration, air filtration, soil stabilisation, habitats for native species, recreation and sense of place (Dhakal et al., 2012; Richard Yao et al., 2013; Richard Yao, Scarpa, Harrison, & Burns, 2019). These multiple values (which include market and non-market values) provided by Whakarewarewa forest are described in Appendix A.

Despite the existence of tools to quantify non-market environmental values, these values remain neglected or overlooked in impact assessments and decision making (Haines-Young & Potschin, 2018; TEEB, 2010; UKNEA, 2011). Reasons why non-market values were not used include hesitance toward the idea of monetising environmental values, prohibitive expense and validity of the estimates (Rogers et al., 2015). However, in New Zealand, biosecurity managers have already had some awareness of these values, for example, they were used to support decision making in responses to addressing the myrtle rust disease affecting both native and non-native Myrteacae (Foote, 2020; P. Tait & Rutherford, 2017).

A growing number of studies suggest that environmental, social and cultural values should be quantified and described using non-market valuation and other techniques to allow their incorporation in biosecurity impact assessments (W. Y. Chang, Lantz, Hennigar, & MacLean, 2012; Foote, 2020; Mazur et al., 2018; Radics, Withers, Meason, Stovold, & Yao, 2018; Stoeckl et al., 2018). One value framework that is gaining increasing attention is the natural capital and ecosystem services (NCES) framework, or more simply just the ‘ES framework’, which: (1) describes a set of tools to quantify and describe the economic and environmental impacts of ecosystem change on human well-being; and, (2) provides approaches to use those quantified values to inform decision making and policy development in New Zealand (Bateman & Mace, 2020; Gale, Richardson, Hutchison, Sullivan, & McCaughan, 2018; Gardiner & Huser, 2017; Polasky, Tallis, & Reyers, 2015; R. Yao et al., 2021).

ES are defined as the goods and services provided by natural and modified ecosystems that benefit, sustain and support human well-being. The ES framework helps to identify, quantify and describe the multiple goods and services provided by an ecosystem (to human beings) and groups them into three categories: (1) provisioning services refer to the material benefits such as logs and timber; (2) regulating services refer to the processes that sustain the environment which indirectly benefit society such as carbon sequestration, water filtration for improving water quality and provision of habitats; and (3) cultural services are the non-material benefits that directly contribute to human well-being such as recreational mountain biking and nature watching (Haines-Young & Potschin, 2018).[1]

One system that supports ES quantification and valuation is the total economic value (TEV) framework. The TEV was developed by environmental economists to account for the multiple non-market values that can be derived from the change in provision of environmental goods and services (McVittie & Hussain, 2013; MEA, 2005; UKNEA, 2011). TEV is based on a human-centred view where value is quantified based on observed choices people make across different competing options while accounting for the fact that resources (e.g., time, money and energy) are finite. A rational individual would choose the option that maximises a person's level of satisfaction and this choice is based on a person's set of preferences, resources and constraints.

TEV is an overarching framework intended to recognise a holistic set of values derived by society from the flow of goods and services. However, it should not be inferred that it is capturing all the diverse types of value that can be derived from the environment (Peter Tait & Rutherford, 2018). It provides a classification of the different ecosystem service benefits to help identify appropriate non-market valuation techniques. The two main categories are based on the way people benefit (i.e., increased level of utility or satisfaction) from either using the environmental resource (*use value*), or being guaranteed that the resource will be used by future generations or will maintain its existence (*non-use value*) (Figure 1). The use value category includes: (1) the direct use or consumption of material goods (e.g., timber, food, drinking water) and the direct non-consumptive use of an environmental amenity (e.g., walking in a forest, mountain biking and educational field trips); (2) indirect use value (e.g., benefiting from on-going carbon sequestration through the reduction of climate change impacts in the future); and (3) option value, for example the conservation of an iconic park that one can potentially visit in the future.

The non-use value category includes bequest value (e.g., the value placed on guaranteeing that future generations will still be able to see endangered bush falcons in NZ planted forests) and existence value (e.g., the value South Island residents, including those who are not likely to go to visit North Island, place on the conservation of the North Island brown kiwi) (Yao et al. 2019) (Figure 1). The existence value category therefore partly covers the intrinsic value (i.e., value of an object for its own sake) of the iconic North Island brown kiwi. This is consistent with Dietz, Fitzgerald, and Shwom (2005) who state that "there are no widely accepted methods for systematically quantifying intrinsic value other than by asking people about the values they assign to a landscape, ecosystem, or species". Furthermore, the Millennium Ecosystem Assessment states that "*…many people do believe that ecosystems have intrinsic value. To the extent that they do, this would be partially reflected in the existence value they place on that ecosystem, and so would be included in an assessment of its total economic value…*" (MEA, 2003). While some argue that a large part of intrinsic value is not accounted for in the willingness to pay for keeping the existence of an environmental good (Attfield, 1998; Davidson, 2013), others argue that "Existence Value = Intrinsic value (i.e. value 'in' things rather than 'of' things)" (Clough & Bealing, 2018; Pearce, 1992). The TEV framework, to a certain extent, covers intrinsic value, thus we connected intrinsic value to existence value with a dashed line in Figure 1.

'Hybrid valuation methods' have also been developed to quantify both anthropocentric and ecosystem-centric values by combining ecosystem service and ecosystem intrinsic value frameworks, for example Sheng, Xu, Zhang, and Chen (2019). More recent assessments of non-market ES values involved combining economic valuation techniques with biophysical and ecological approaches (Daniels et al., 2017; Richard Yao et al., 2019) and with social science approaches (Tobias Börger & Hattam, 2017) to deliver more holistic and inclusive non-market value estimates.

[1] In the original ES framework, there is a fourth category of services called supporting services which include nutrient cycling and primary production (MEA, 2003). As we are discussing quantification and valuation, we elected not to mention that category as the valuation of those services would lead to double counting (Fu et al., 2011; Haines-Young & Potschin, 2018).

The quasi-option value category is indirectly linked with both use and non-use values. The motivation for creating this value category was to represent the benefits of delaying a major decision until more information becomes available. Unlike the value individuals place on changes in ES provision, this value represents the “welfare gain associated with delaying a decision when there is uncertainty about the payoffs of alternative choices, and when at least one of the choices involves an irreversible commitment of resources” (Freeman, Herriges, & Kling, 2014). This value also represents the benefits that people can derive from nature’s unknown uses or non-uses in the future (P. Tait & Rutherford, 2017).

In non-market valuation, we estimate the human well-being value based on the change in provision of the flow of ES. This value “is often referred to as a ‘benefit’(‘cost’) if it raises (lowers) well-being” (Ian Bateman et al., 2011). This *value* of an ecosystem good is not equivalent to its *market price* and this can be explained by going back to our earlier example, i.e., the Whakarewarewa forest in Rotorua. There is no entrance fee to enter in most parts of this forest, so the market price of a visit is zero. However, when people visit and recreate (walking, running or mountain biking) in the forest, they allocate their limited time for recreation and incur transportation cost to get to the forest; therefore, the imputed value of time and transport cost (plus other factors) can serve as a proxy visitation value for the forest user. This value of a forest visit can be approximated using the travel cost method which estimates the recreational use value based on the observed behaviour of forest users. As no tangible objects or materials are consumed during recreational walking visits, this is also referred to as a non-consumptive use value of the forest (Figure 1).

Some use values that an ecosystem provides can be estimated using price-based valuation methods such as production function, avoided cost and expenditure approach. As the values used in price-based methods are observed in market transactions, the calculation of their values is straightforward. Descriptions and examples of this group of methods are presented in Table 1.[2]

Travel cost and price-based valuation methods can quantify use values but not non-use values (IanJ Bateman et al., 2011). Stated preference approaches such as choice experiment and contingent valuation are survey-based techniques that provide respondents with simulated or hypothetical markets (Johnston et al., 2017). They elicit the value placement of respondents by directly or indirectly asking, using carefully framed survey questions, the amount that they would be willing to pay or accept for a hypothetical change in provision of an environmental good from the current level of provision (Tobias Börger & Hattam, 2017). Stated preference approaches are based on how people maximise their utility based on their choices which are anchored on their preferences. This approach is helpful to answer the question what most of society values when it comes to the change in the provision of an environmental good (e.g., willingness to pay for the conservation of brown kiwi in NZ planted forests) and how this value would likely be impacted by a pest incursion (Stoeckl et al., 2018).

Benefit transfer is a non-market valuation technique that uses existing estimates of ecosystem service benefits from one place and time (i.e., from completed economic valuation studies) and transfers these estimates to another time at the same place or to a new place with the help of a ‘transfer function’ (Boyle & Parmeter, 2017). This method gained popularity because of its cost effectiveness; however, it has also been questioned when it comes to the internal validity of value estimates (Newbold et al., 2018). Johnston, Boyle, Loureiro, Navrud, and Rolfe (2021) provide recommendations to enhance the validity and credibility of environmental benefit transfers based on research experience and the literature.

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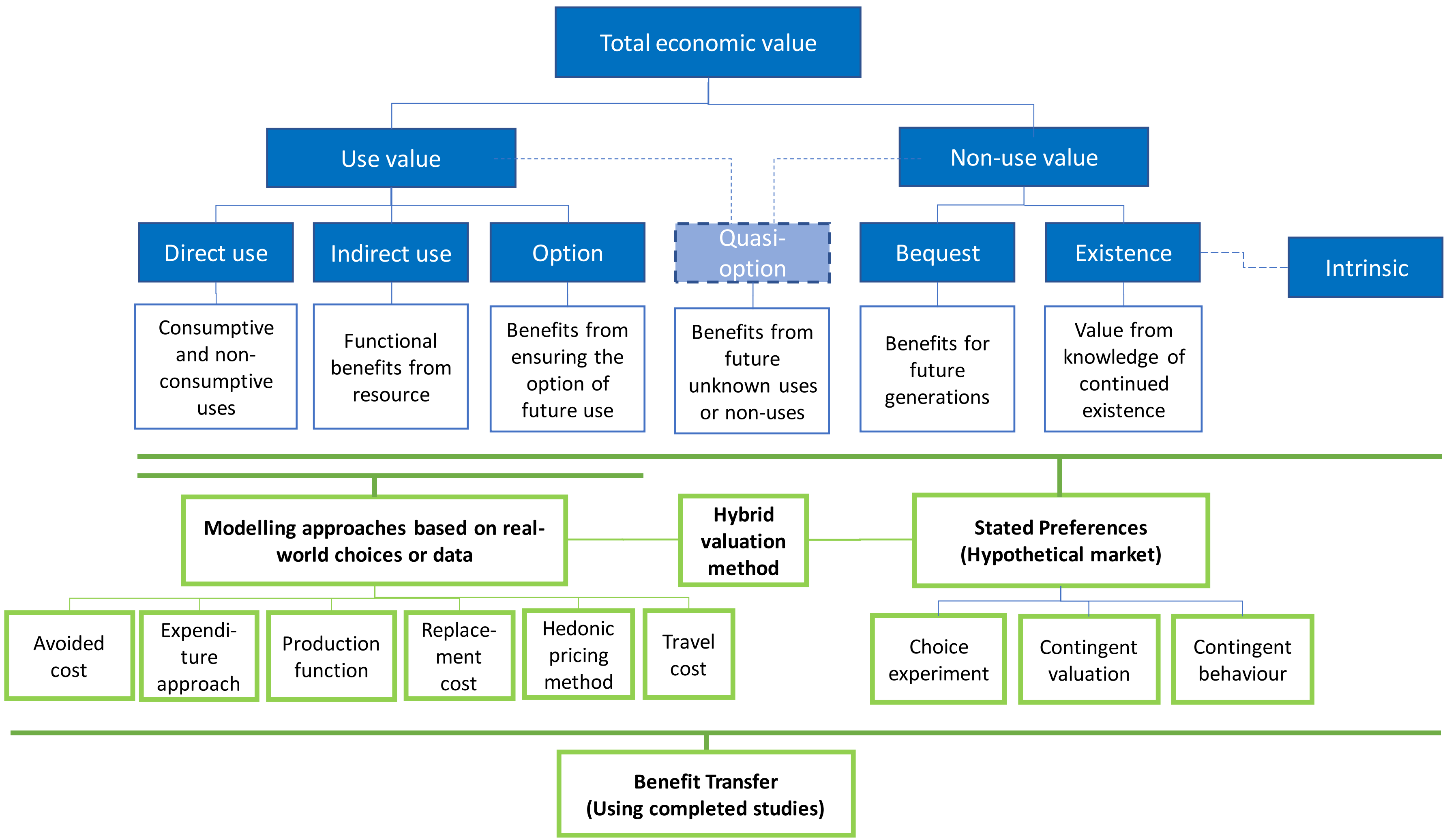
[2] This report aims to provide brief overviews of non-market valuation methods. For more details of valuation methods and guidance for undertaking valuation surveys, please refer to I. Bateman, G. Mace, C. Fezzi, G. Atkinson, and K. Turner (2011) and Johnston et al. (2017), respectively.

**Table 1:** Non-market valuation and hybrid methods for quantifying ecosystem service benefits.

| Valuation method | Value type | Description of method | Types of applications | ES valued | Example studies |
|---|---|---|---|---|---|
| ***Revealed preference methods – valuation models based on real-world choices*** | | | | | |
| Production function | Use | Estimation of production functions to isolate the effect of ES as inputs to the production process. | Environmental impacts on economic activities and livelihoods, including damage costs avoided, due to ecological regulatory and habitat functions. | Maintenance of beneficial regulating services in ecosystems (e.g., nutrient sequestration in marine sediments); prevention of damage from erosion and siltation; groundwater recharge. | See Gren, Nyström Sandman, and Näslund (2018) |
| Avoided cost | Use | Calculates the cost avoided by maintaining, sustaining or enhancing the flow of ES | Afforestation of marginal lands | Avoided sedimentation of waterways | Barry, Yao, Harrison, Paragahawewa, and Pannell (2014) |
| Expenditure approach | Use | Includes all expenditures to avoid or reduce damage to the environment | Environmental protection | Valuing the protection service provided by ecological infrastructure (e.g., storm protection of mangroves) | Mahmud and Barbier (2016) |
| Travel cost method and hedonic pricing method | Use | Examines the expenses incurred on ecosystem related goods, e.g., travel cost for recreation; hedonic (usually property value) prices in areas with high water quality | Recreation; residential property values | Forest recreational visits; improved water quality | See Dhakal et al. (2012) for travel cost method and Woodham and Marsh (2011) for hedonic method |
| ***Stated preference methods – valuation models based on hypothetical or simulated markets*** | | | | | |
| Choice experiment and contingent valuation | Use and non-use | Uses surveys to ask individuals to make choices between different levels of environmental goods at different prices to reveal their willingness to pay for those goods | Conservation benefits; pest control benefits | Conservation of iconic native species in planted forests; social benefits of controlling insect pest outbreaks | See Yao et al. (2019) for choice experiment and W.-Y. Chang, Lantz, and MacLean (2011) for contingent valuation |
| ***Valuation method based on completed studies*** | | | | | |
| Benefit transfer | Use and non-use | Uses existing estimates of ecosystem service benefits from one place and time and transfers to another time at the same place or to a new place | Environmental benefits of controlling invasive species | Biodiversity conservation and recreation; avoided nitrate leaching | Wainger et al. (2018); Radics et al. (2018) |
| ***Hybrid methods – combining non-market valuation technique/s with other approaches*** | | | | | |
| Production function combined with Simulation modelling | Use | Linking an ecological simulation model with an economic model to evaluate the impact of a reduction in biological pest control services | Primary industry benefits | Maintenance of beneficial species (i.e., natural pest predators) in pear orchards | Daniels et al. (2017) |
| Hedonic pricing model combined with Difference-in-differences | Use | Helps compare property values between those with and without invasive species | Benefits to property owners | Property price premium of having no invasive species | Horsch and Lewis (2009) |

Adapted from Ian Bateman et al. (2011)




Adapted from (I. J. Bateman, G. M. Mace, C. Fezzi, G. Atkinson, & K. Turner, 2011; Baveye, Baveye, & Gowdy, 2013; Davidson, 2013; Peter Tait & Rutherford, 2018)

**Figure 1:** The total economic value framework.

# Methods and Data

## Methods

A systematic literature review was undertaken between May and August 2021. The review followed the established systematic review methodology to synthesise and generate results based on a structured, replicable, and pre-defined research question, search criteria, and a data classification template (Higgins et al., 2021; Petticrew & Roberts, 2006). We set the following inclusion and exclusion criteria to facilitate filtering of the literature on the title, abstract and full-text levels:

Criteria for inclusion:

- Biosecurity focus
- Empirical study
- Quantifies or measures the value of environmental ES and/or the value of changes in provision of environmental ES (e.g., valuation methods based on hypothetical behaviour, observed behaviour, and/or alternative valuation methods)
- Valuation methods described
- Context/setting of valuation described

Criteria for exclusion:

- Lack of biosecurity focus
- Conceptual, theoretical or review focus
- Does not quantify or measure value of environmental ES
- Valuation methods not described
- Context/setting of valuation not described

Using Scopus, a global literature search was undertaken in May 2021. We used the Scopus search string in Figure 2 which produced bibliographies and abstracts from 775 publications.

```
( ( TITLE-ABS-KEY ( quantification  OR  "decision making"  OR  "Non-market valu*"  OR  "contingent
valuation"  OR  "ecological valu*"  OR  "travel cost"  OR  "choice experiment"  OR  "market price"  OR
"hedonic pricing model"  OR  "benefit transfer"  OR  "contingent behaviour"  OR  "spatial economic" ) )
AND  TITLE-ABS-KEY ( ( ( invasive  OR  non-native  OR  introduced  OR  biosecurity )  AND  species )
OR  biosecurity )  AND  TITLE-ABS-KEY ( "outdoor pursuits"  OR  "nature watching"  OR  "environmental
knowledge"  OR  "environmental education"  OR  recreation*  OR  amenit*  OR  tourism  OR  "genetic
resources"  OR  "ecosystem function"  OR  "native dominance"  OR  conservation  OR  ( air  AND  quality )
OR  ( soil  AND  conservation )  OR  aesthetic*  OR  erosion  OR  ( "natural hazard"  AND  regulation )  OR
"ecosystem service"  OR  ( carbon  AND  sequestration )  OR  ( climate  AND  regulation )  OR  ( nutrient
AND  ( cycl*  OR  regulation ) )  OR  ( water  AND  ( cycl*  OR  quantity  OR  quality  OR  purification ) )
OR  "flood control"  OR  pollination ) )
```

**Figure 2:** Scopus search string script.

## Data

We analysed 775 abstracts and found a substantial proportion to be irrelevant for this research. We filtered these studies out and reduced our literature database to 147 studies. We conducted further filtering on the full-text level, excluding 88 studies due to environmental values not being measured or quantified (48 studies); a conceptual, theoretical or review focus (18 studies); values not being explicitly categorised as environmental values (7 studies); valuation methods not being described (5 studies); duplicate values to other studies in the search results (4 studies); non-English language publications (3 studies); or a lack of biosecurity focus (3 studies) (Figure 3).

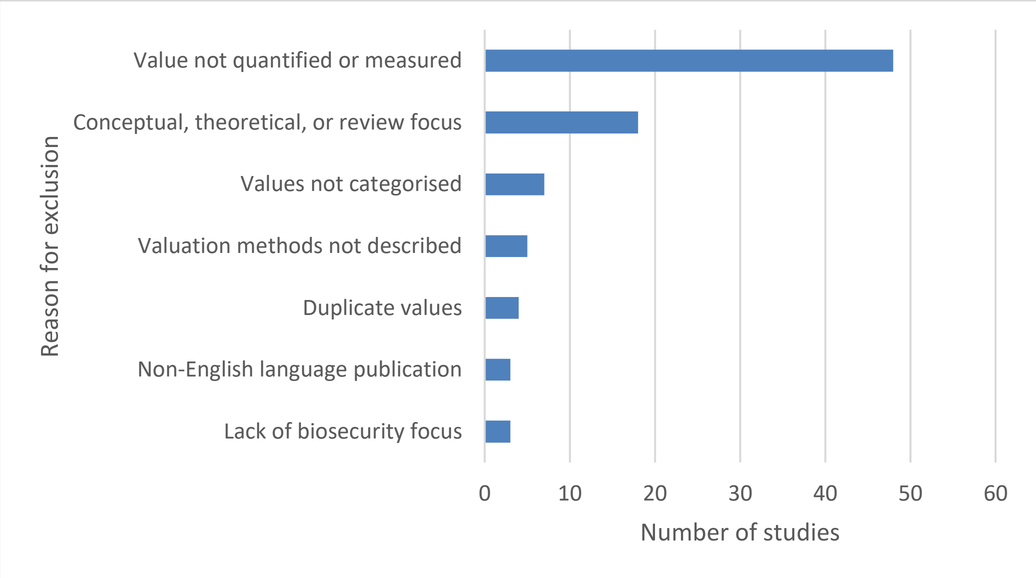



**Figure 3:** Distribution of studies by reason for exclusion from the final body of literature

The final body of literature included 59 studies from the Scopus search which matched our inclusion criteria. We also identified sixteen relevant studies using current knowledge and experts in the field. These studies were added to the list resulting in a total of 75 studies that were published between 2000 and 2021 (Appendix B). These studies were examined to identify and extract human-centred environmental values.

We organised the data in the literature for analysis through a data extraction template summarising indicator, topic, scale, location, ecosystem type, type of pest, year of analysis, valuation method/s, model/s used, elicited environmental values, value unit, factors influencing valuation, study assumptions, study limitations and bibliographic information for each study.

To facilitate relative comparisons of environmental values, we converted all monetary values extracted from the literature to New Zealand dollars (NZD) for the year they were reported (OANDA, 2021). In cases where the year of the reported value was unclear, we used the study's year of publication. We then used Reserve Bank of New Zealand's Inflation Calculator tool to adjust converted values to Quarter 1 2021 NZD (Reserve Bank of New Zealand, 2021).

# Results

## Literature overview

Results from the literature review indicate that studies measuring environmental non-market ES values in the biosecurity context have steadily increased between 2000, the year the first study in our body of literature was published, and 2021 (Figure 4). The number of ES valuation studies related to biosecurity protection increased more than five-fold from five studies in years 2000–2005 to 28 studies in years 2016–2020. This shows a trend of increasing importance of ES valuation in the biosecurity space over the past two decades.

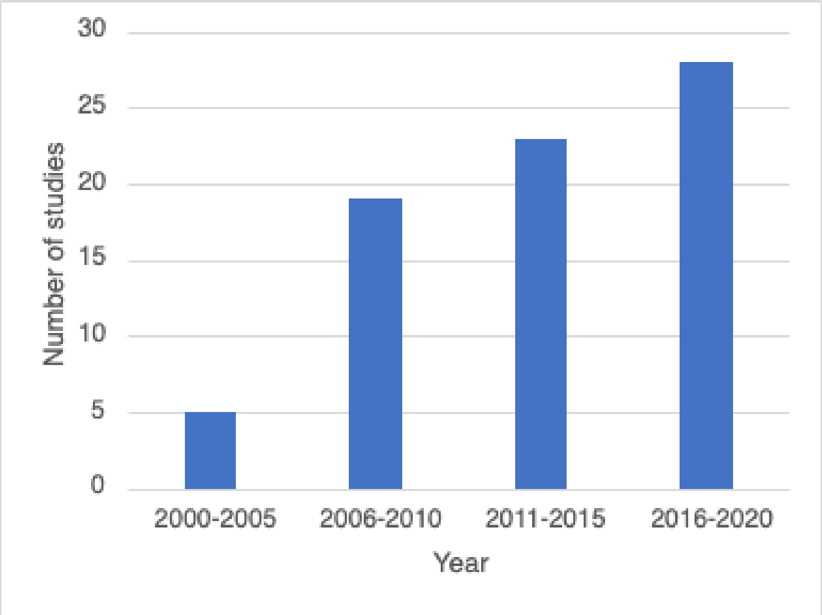



**Figure 4:** Distribution of studies by year published

The majority of studies were conducted in North America (43%) and Oceania (23%) followed by Europe (15%) and Africa (12%) (Figure 5). We found less work being undertaken in Asia (7%) and South America (1%), though we acknowledge that our focus on English-language literature may have biased the search results. Out of the 17 ES valuation studies conducted in Oceania, nine (53% of Oceania) studies were carried out in New Zealand.

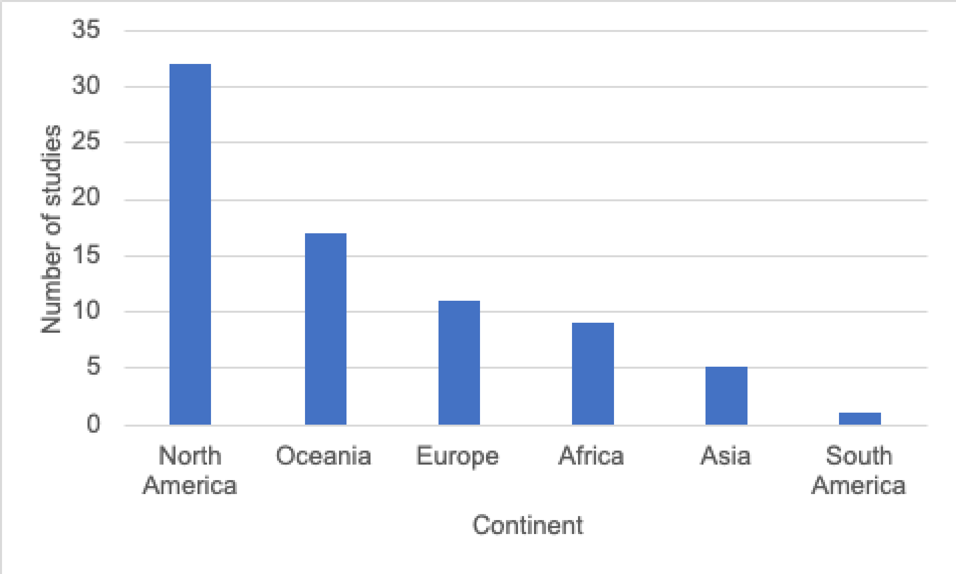



**Figure 5:** Distribution of studies by case location

Figure 6 demonstrates the flexibility of non-market valuation methods as they can be applied across different scales of analysis. 35 studies concentrated on the regional scale (ranging from county or district-level to inter-state or province). 15 studies were national in scope and 13 studies focused on the state or provincial scale, with a smaller number of studies analysing transnational (inter-European or multiple countries in Europe), city, or park-level scales (1, 2 and 9 studies respectively).

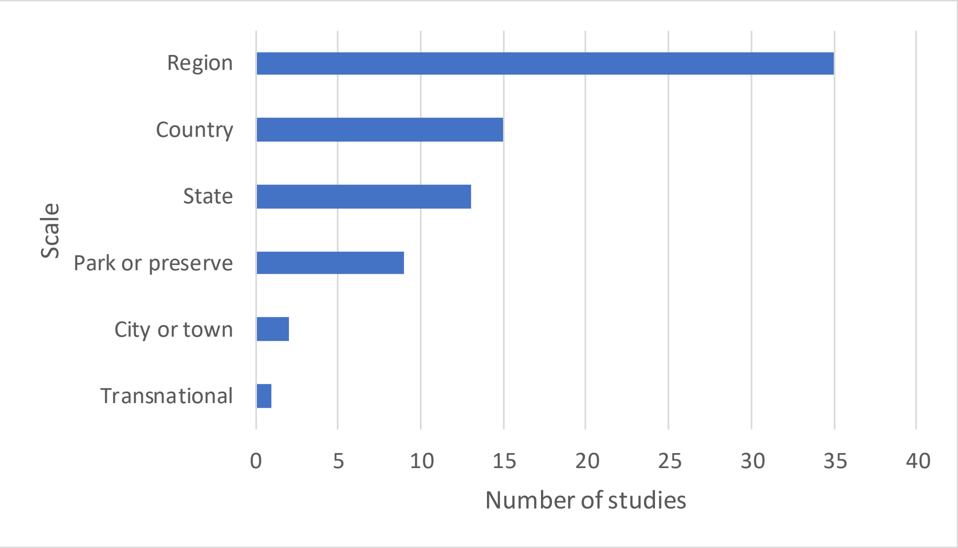



**Figure 6:** Distribution of studies by case scale

Figure 7 illustrates the distribution of studies by the type of ecosystem analysed. 29 studies (38%) examined aquatic environments, specifically freshwater ecosystems (18 studies) and coastal and marine settings (11 studies). Four additional studies focused on island environments comprising both aquatic and terrestrial ecosystems. The remaining 42 studies analysed terrestrial ecosystems, with forest ecosystems being the most prominent area of focus (23 studies). Eight of the 42 studies either failed to specify the type of terrestrial ecosystem being investigated or included more than one type of terrestrial ecosystem in their analyses. Six studies analysed modified or developed ecosystems, including farmed fields, rangeland, and urban environments. A smaller number of studies concentrated on mountain environments (2 studies), wetlands (1 study), areas of remnant vegetation (1 study) and heritage garden settings (1 study).

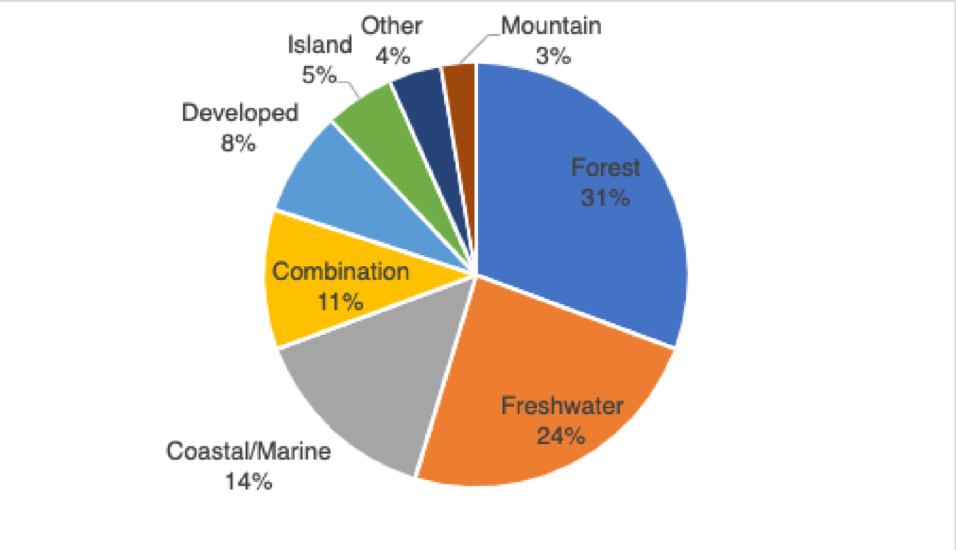



**Figure 7:** Distribution of studies by ecosystem type. Developed includes farmed fields, rangeland, and urban environments.

The studies measured the impacts of different types of non-native invasive species and native pest species in the biosecurity context (Figure 8). Across all types of species analysed in the studies, terrestrial plants comprised 21% of the pests studied, followed by insects (17%), aquatic plants (14%), mammals (11%), aquatic invertebrates (9%), uncategorised aquatic species (9%), pathogens (including plant pathogenic microorganisms and fungi) (7%), uncategorised combinations of pests (6%) and aquatic vertebrates (6%). We note that some studies analysed the same type of pest in different locations and contexts such as: (1) Eurasian watermilfoil (Eiswerth, Donaldson, & Johnson, 2000; Horsch & Lewis, 2009; Lewis, Provencher, & Beardmore, 2015; Zhang & Boyle, 2010); (2) emerald ash borer (Arnberger et al., 2017; Jones, 2017, 2018; Kovacs et al., 2010); and (3) water hyacinth (Van Oijstaeijen et al., 2020; Wainger et al., 2018).

All but three of the 75 studies focused on the environmental and well-being impacts of controlling non-native pests. Conversely, W.-Y. Chang et al. (2011), W. Y. Chang et al. (2012) and Nunes et al. (2015) analysed the biosecurity control impacts of native pests including spruce budworm and forest tent caterpillar in Canada, spruce budworm in Canada, and jellyfish on the Catalan coast of Spain, respectively.

While the majority of studies concentrated on the negative impacts of pest species, a small number of studies analysed these species' potential *benefits*, including the use of the Prosopis tree for microclimate regulation in Ethiopia and Kenya (Bekele, Haji, Legesse, & Schaffner, 2018), the pollinator foraging provisioning services provided by *Eucalyptus cladocalyx* in South Africa (De Lange, Veldtman, & Allsopp, 2013), and the recreational value associated with fishing for non-native species in South Africa (du Preez & Hosking, 2011) and the United States (Raynor & Phaneuf, 2020).

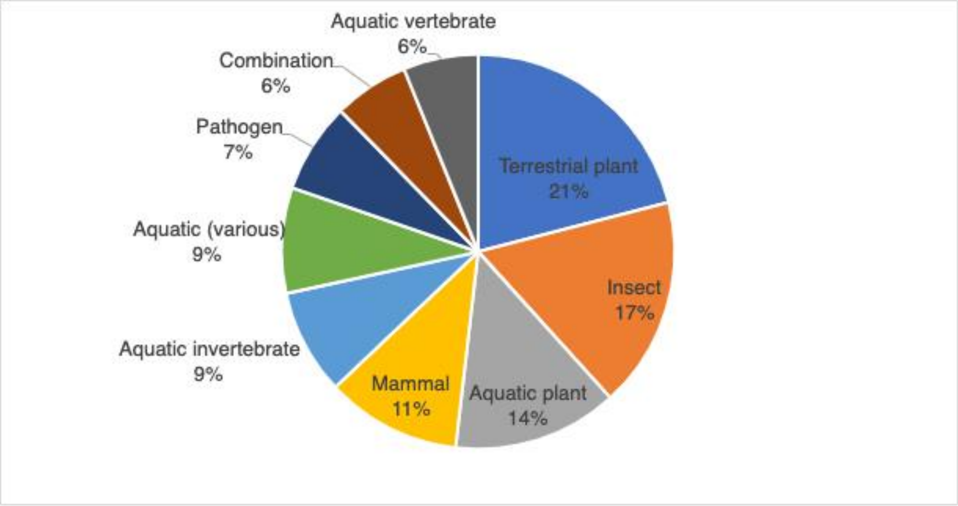



**Figure 8:** Distribution of studies by type of pest

Figure 9 depicts the methods used to measure various environmental values in the studies. Across the 75 studies compiled, 101 ES valuation/quantification methods were employed. The method count is greater than the total number of studies because 15 studies (20%) employed a non-market valuation method in conjunction with one or two other methods, thereby developing a hybrid non-market ES valuation approach. For example, Weber and Stewart (2009) used both contingent valuation and choice experiment to estimate the value of a potential pest control programme that would ensure wildlife conservation in a river system in New Mexico. Daniels et al. (2017) used an ecological simulation model in conjunction with the production function approach to undertake a monetary valuation of natural predators for biological pest control of pear fruit trees.

Stated preference techniques (e.g., choice experiment and contingent valuation methods) were collectively used in the two largest groups of studies analysed, with choice experiments used in 29 studies (39%) and contingent valuation used in 19 studies (25%). This indicates that a large majority of the study leaders recognised the importance of estimating both use and non-use ES values in evaluating the social welfare impacts of biosecurity protection initiatives.

The direct market valuation approach, which includes replacement cost, production function, avoided cost and expenditure approach, was employed in 14 studies (19%). Benefit transfer was adopted in 10 studies (13%), while 7 other studies employed different types of simulation approaches for example developing simulation models to forecast the potential future impacts of pest species. Other methods that were used less frequently included travel cost, difference-in-differences, surveys (not related to willingness-to-pay) and hedonic pricing model.

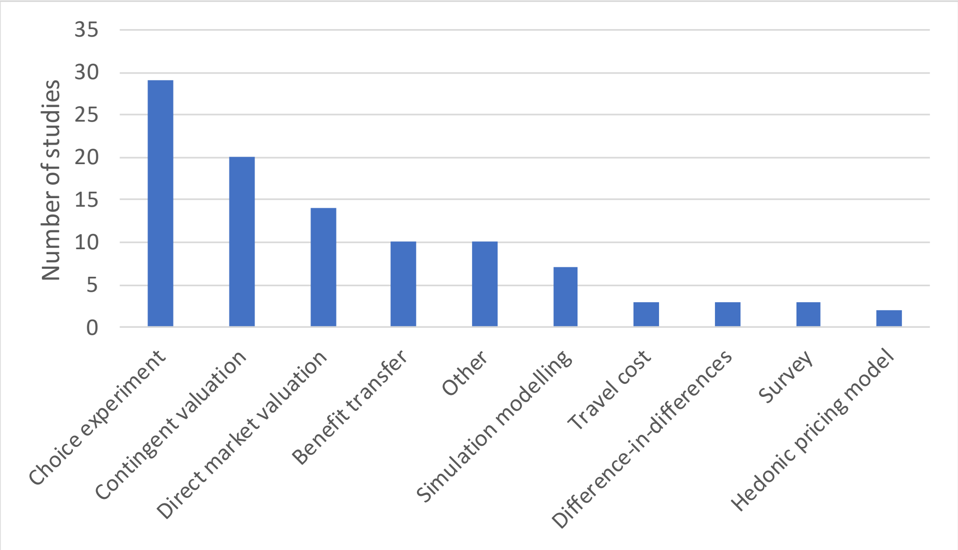



**Figure 9:** Distribution of studies by valuation method

Our literature search broadly focused on studies measuring environmental values provided by biosecurity initiatives using ES valuation techniques. The largest number of studies (51 studies or 68% of the total) evaluated the non-market values of conservation and environmental protection, including protection of native species (Mazur et al., 2018; Richard Yao et al., 2019) (Figure 10). 28 studies analysed various aspects of biosecurity protection impacts on nature-based recreation such as forest visits (W.-Y. Chang et al., 2011; Drake & Jones, 2017), beach visitation (Nunes et al., 2015) and fishing (Beville, Kerr, & Hughey, 2012; du Preez & Hosking, 2011). 11 studies either failed to specify a specific topic or drew on a combination of topics, such as forest ES which may encapsulate a range of environmental values. Nine studies focused on valuing landscape and aesthetic values. A small number of studies evaluated impacts of pests on human health and well-being values such as life satisfaction, infant birth weight, gestation time, and healthcare costs (5 studies, including three by the same author (Jones, 2017, 2018, 2019)). As with the distribution of the valuation methods used in the studies, the topic count is greater than the total number of studies because several studies examined more than one topic.

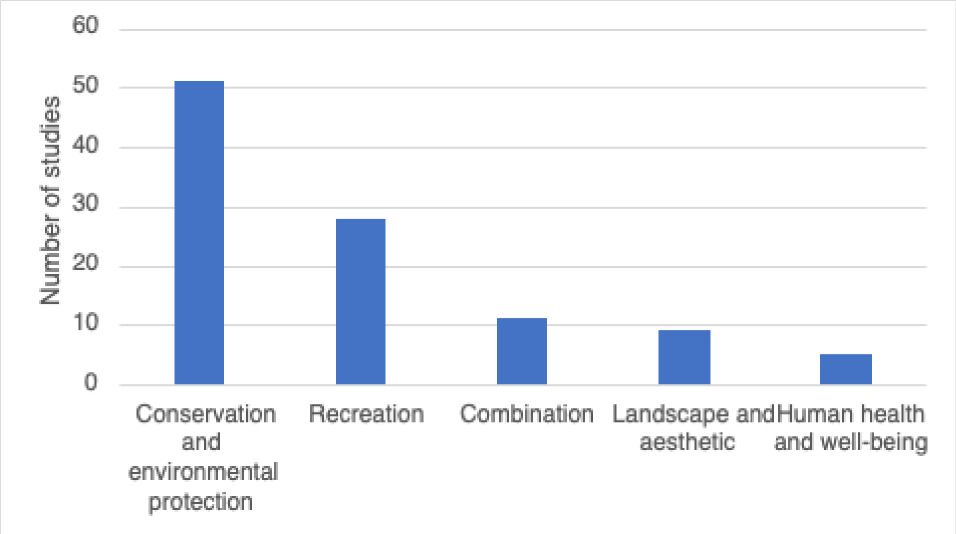



**Figure 10:** Distribution of studies by type of ecosystem services and human well-being benefits.

## Summary of values

We now turn to the quantified environmental values extracted from the literature. Given the range and diversity of outcomes analysed by the studies, we acknowledge that it is almost impossible to meaningfully compare monetary values across studies without the aid of a formal meta-analysis. We therefore aim to identify patterns and trends in the literature, while adding rich systematic datapoints to the NMV reviews that already exist. Similar to the findings of Clough and Bealing (2018), we find that the body of non-market valuation studies for biosecurity initiatives remains very thinly spread or patchy. We also find a lack of standardisation in the measurement of values provided by biosecurity initiatives and this results in a wide range of units across and even within studies, adding to the challenge of cross-study comparison. In total, the studies employed 54 distinct units of measurement ranging from monetary amount in household per year (59 values), to neighbourhood per five-year period (5 values), to million gallons lost per year (2 values) (see Appendix C for the distribution of studies by value unit). For the purposes of our illustrative summary, and due to differences in the units used to measure values, we thus focus on only a small proportion of the 729 values extracted from the studies.

Table 2 provides a summary of the compilation of the 96 non-market environmental values extracted from our body of literature that were measured on a per household per year basis. We grouped the values into several broad themes: (1) increased plant abundance and richness; (2) increased animal abundance and richness; (3) terrestrial environmental improvement; (4) water and coastal environmental improvement; (5) reduction in spread of invasive plants; (6) reduction in spread of invasive insects; (7) reduction in spread of invasive non-insect animals; and (8) reduction in spread of invasive pathogens. While broad in nature, the groupings suggest that values relating to human health, for example, are less studied in the NMV context than more traditional “ecological” values. They further exemplify the two streams of analysis found in the biosecurity-focused NMV literature, in which authors measure both the value of an environmental outcome (e.g., willingness to pay for the preservation of a particular species) and the value of different management initiatives which will ostensibly lead to a reduction in the number of pests (e.g., willingness to pay for the implementation of an insect control initiative). We find that these dual measurements often take place within the same study.

**Table 2:** Summary of estimated environmental values in 2021 NZ$ per household per year.

| Outcome | Mean (NZ$) | Median (NZ$) | Number of studies |
|---|---|---|---|
| Reduction in spread of invasive plants | 138.89 | 21.49 | 21 |
| Increased plant abundance and richness | 110.23 | 90.29 | 10 |
| Increased animal abundance and richness | 105.32 | 90.43 | 21 |
| Environmental improvement (terrestrial) | 92.80 | 76.88 | 10 |
| Reduction in spread of invasive insects | 92.20 | 99.11 | 10 |
| Reduction in spread of invasive non-insect animals | 78.47 | 93.53 | 10 |
| Environmental improvement (water and coastal) | 29.34 | 27.46 | 8 |
| Reduction in spread of invasive pathogens | 5.17 | 11.50 | 6 |

While it may be possible to draw broad comparisons between the mean and median values presented for each grouping in Table 2, these values belie a range of specific outcomes. For example, the increased plant abundance and richness grouping included the estimated value of a general increase in the quality of forest cover from “medium” to “high” cover (van Beukering, Grogan, Hansfort, & Seager, 2008), alongside the amount city residents were willing to pay for total success in preserving 21% of the charophytes (a group of green algae) cover in a nearby lake (Bell, Yap, & Cudby, 2009). The non-market valuation for increased animal abundance and richness similarly included both general biodiversity outcomes (e.g., the value of plentiful birds and insects in Kerr and Sharp (2008) and values associated with specific species (e.g., an increase in the banded anteater population to 400 animals in five years’ time in Subroy, Rogers, and Kragt (2018); and an increase in the protection of porpoises, seals, and seabirds from no protection to protected on 50% of an offshore marine protected area in T. Börger, Hattam, Burdon, Atkins, and Austen (2014). Environmental improvement in water and coastal areas included the value of an increase in water availability from only the summer season to two seasons (Bekele et al., 2018), while environmental improvement in terrestrial settings measured values such as the benefit to households of preventing the build-up of large blocks of wilding conifers (Kerr & Sharp, 2007).

Several studies attempted to analyse the value of invasive species management interventions with the goal of a reduction in their spread. Within the invasive plant grouping, specific values ranged from the annual willingness to pay for an invasive tree management option that would improve ES (Bekele et al., 2018), to the increased amount of annual income tax respondents were willing to pay to support management interventions against a list of invasive plant species (Junge, Hunziker, Bauer, Arnberger, & Olschewski, 2019).

Values associated with invasive insect management included households’ willingness to pay for controlling future forest insect outbreaks in provincial forests (W.-Y. Chang et al., 2011; W. Y. Chang et al., 2012) and the willingness to pay to reduce the impact of fire ants per 1,000 private homes (Rolfe & Windle, 2014). Invasive pathogen management analysed willingness to pay for forest disease control based on forest ownership structure (Sheremet, Healey, Quine, & Hanley, 2017).

Finally, the invasive non-insect animal grouping looked at respondents’ willingness to pay for various methods of fox and feral cat management, compared to the status quo strategy of pesticide application (Subroy et al., 2018).

In spite of these significant differences in quantified outcomes, we found several different patterns emerging from the groupings. We included 10 values in the plant abundance and richness grouping (Table 2). Five of these values related to the value of maintained or increased plant species cover (e.g., maintenance of 21 percent charophyte cover in a lake) and an increase in forest cover from “medium” to “high” cover). The remaining values were associated with plant diversity – for instance, the value of an increase in native tree proportion compared to the status quo of non-native tree dominance or a more general increase in plant species “richness”. We found a greater number of values (21 values) in the animal abundance and richness grouping (Table 2). The vast majority (17 of 21 values) focused on a particular species or group of species (preservation and or protection of shags; fish/mussel species; porpoises, seals, and seabirds; numbats; woylies; kiwis; bush falcons; and geckos), while four others valued the more abstract outcomes of the existence of plentiful birds and insects; an increase in the level of species abundance from "threatened species" to "abundant species"; and a 10 percent increase in the fish and wildlife population compared to the current population. A starting point for cross-study comparison may be to further separate these values into sub-groupings that include species-specific and more general species protection outcomes.

Values in the terrestrial environmental improvement grouping were concerned exclusively with forest quality and type, though the grouping included only two studies (Kerr & Sharp, 2007; Weber & Stewart, 2009). Kerr and Sharp (2007) analysed the value of avoiding the establishment of large blocks of wilding conifers in different locations throughout New Zealand, while Weber and Stewart (2009) asked respondents how they valued different management regimes resulting in proportions of native versus non-native trees in a riverside recreational area. The eight values in the water/coastal environmental improvement grouping related to water quality and availability along with general protection of coastal and adjacent waters with different levels of success probability.

The grouping that analysed the value of a reduction in the spread of invasive plants included 21 values. Almost half of the values (10 of 21 values) related to the removal or prevention of aquatic plants such as hydrilla, milfoil, and water hyacinth. Of these 10 values, six valued a management option resulting in complete removal of the invasive plant from the body of water, an outcome that authors acknowledged may or may not be feasible. The other values measured maintenance of current levels or a prevention approach which would make an aquatic plant invasion “highly unlikely”. We found a greater diversity in the payment method in the invasive plant management grouping versus other groupings (from traditional WTP to the value of the number of days of labour a household is willing to contribute to invasive tree management to the opportunity cost of labour for every day involved in invasive plant species management), perhaps owing to the presence of different geographical and cultural contexts in this grouping, including studies from Ethiopia, Kenya, and Nepal alongside Europe and the United States.

The 10 values comprising the grouping concerned with a reduction in spread of non-insect animals were extracted from the same study (Subroy et al., 2018), and are therefore more amenable to comparison than the majority of the values extracted from the literature. This study analysed respondents’ willingness to pay for different combinations of fox and feral cat management interventions. Results suggest that alongside the environmental outcome achieved, the type of intervention used is also important, with respondents generally willing to pay more for interventions, or combinations thereof, including fencing and trapping than they were for the status quo of 1080 pesticide application on its own (marginal WTP ranging from $64.40 to $149.75), with the exception of a community engagement strategy on its own.

In their analysis of forest disease control in the United Kingdom, Sheremet et al. (2017) similarly found that respondents desired higher compensation for the clear felling method ($17) versus a biocide approach ($12). However, the majority of studies in our review only looked at the value of a single type of management intervention, if a particular type was specified at all.

The invasive pathogen management grouping likewise included six values from the same study (Sheremet et al., 2017). The study analysed WTP for disease control in different forest environments and found that respondents were willing to pay more for disease control in forests owned by wildlife charities ($19) or the national authority ($18) versus forests owned by the local authority ($10) and compared to the baseline of family-owned forests. Similarly, the invasive insect management grouping and the value respondents placed on controlling future forest insect outbreaks in different Canadian provinces (W.-Y. Chang et al., 2011) and reducing the impact of fire ants on different land-use types in Brisbane, Australia (Rolfe & Windle, 2014). Like the studies described above, these results reiterate the importance of the method and context of biosecurity interventions alongside the final environmental outcome.

# Discussion

## Use of non-market environmental values

Environmental values from the point of view of society continue to remain poorly understood and are often overlooked in decision making. Non-market valuation (NMV) methods which help provide approximations of environmental values are continuously developed to quantify and describe these public environmental values to enable their representation in decision making. NMV methods often provide monetary estimates of public values to allow an apple-for-apple comparison of public benefits provided by an ecosystem (e.g., conservation of native species in planted forests) with the financial cost of conservation (e.g., cost of predator control) and market access benefits. For example, controlling predators such as stoats and other mustelids to conserve the North Island brown kiwi in exotic NZ planted forests is valued by New Zealanders. Yao et al. (2019) demonstrated that for every dollar invested in a potential government coordinated five-year kiwi conservation programme in planted forests, a typical New Zealander would get about $100 in public benefit which is represented by the willingness to pay to protect the brown kiwi from pests (including both use and non-use values). This result highlights the importance of encouraging such initiative or similar public-private conservation partnerships as it is an efficient use of scarce resources while offering an opportunity for the government, industry and the general public to work together. Yao et al. (2019) co-designed this NMV study and cost benefit analysis with inputs from conservation specialists, geo-spatial analysts, government agencies, forest industry, non-government conservation organisations and the general public. That study used choice experiment in combination with ecological and spatial approaches and the valuation scenario was co-designed with the industry, government agencies and the general public.

Rogers et al. (2015) interviewed 38 representatives from government and natural resource management organisations in Australia and found that a significant proportion (37%) of the respondents used non-market valuation as an input to decision making. Like the results of our literature review, they found that choice experiment (57%) and benefit transfer (36%) were two of the most used NMV methods. They also found that although a large proportion of the respondents were unfamiliar with non-market valuation, they stated (after the introduction of the different NMV techniques) that NMV could potentially serve as a useful tool for environmental decision making. One reason for NMV's usefulness was that it "offers an evidence-based approach for decision-making and that it can put an order of magnitude on benefits and costs of environmental projects". Respondents were also asked "In what ways are nonmarket values used?", and their top responses include "to **justify** additional expenditure on protecting native species"; "to **support** limits on water allocations"; and "**critical for securing** on-going funding [of the existing project]".

Foote (2020) conducted a meta-analysis of 128 NMV studies in New Zealand and interviewed four biosecurity managers, three NMV subject matter experts and three Māori representatives to evaluate the importance of NMV in biosecurity decision making. From the meta-analysis, it was found that 'risk reduction' was valued by the smallest proportion of the studies (only 8%) and there was also a lack of biosecurity specific representation in the NMV database. Results of the interviews indicated that NMV was regarded as a tool that equips biosecurity decision makers with important supporting information that considers the values and opinions of the general public and potentially iwi. Foote added that 'The primary benefit of the [NMV] approach would avoid opinion-based, opaque decisions, which can often lead to under-estimating non-market benefits.' NMV estimates, especially those that employed stated preference approaches, like contingent valuation and choice experiments, can help impute values for unpriced or intangible effects of biosecurity protection programmes (Smith & Clough, 2000; Peter Tait & Rutherford, 2018). Therefore, NMV contributes to more transparent and inclusive biosecurity risk assessment and decision making compared to using only relevant financial market values.

New Zealand's Greater Wellington Regional Council (GWRC) has undertaken a cost benefit analysis (CBA) combined with an impact assessment for the Proposed Regional Pest Plan 2019-2039. One objective of that CBA was to provide an understanding of the broader values (e.g., biodiversity, amenity and other environmental, social and cultural values) that may be impacted by the absence of any management of the listed pests, and the likely significance of these impacts. The extended CBA included the indicative non-market ecosystem service values or public environmental values provided by rivers and lakes (i.e., recreational values) (Gale et al., 2018). That CBA evaluated whether the combined value of market and non-market benefits of each of the proposed pest management programme outweighs the cost of the set of interventions.

Estimated values should be treated with caution as each estimate has an underlying uncertainty. To account for this level of uncertainty, most studies report their estimated NMVs with measures of central tendency and spread (median, mean, min, max and confidence intervals) (Freeman et al., 2014). This range of non-market values provides more information for conducting generalisable cost benefit analyses that employ simulation techniques enabling the incorporation of probability distributions (Dalziel & Hulme, 2016; Treasury, 2015). Cost benefit analyses that incorporate these non-market monetary ES values would complement multi-criteria analysis that integrate additional dimensions and allow decision makers to rank options based on their criteria (Martin & Mazzotta, 2018; R. Yao et al., 2021). In addition, estimated non-market environmental values can also be used as one of the input sets for undertaking other decision support tools such as computable general equilibrium (Carbone & Kerry Smith, 2013).

## Limitations of non-market valuation (NMV)

The different NMV biosecurity studies from the literature review used different methods (e.g., choice experiment, contingent valuation and benefit transfer). Even when a group of studies applied the choice experiment method, each study within the group had a unique survey design and ways of quantifying and reporting the values. Although they may follow well-established economic valuation methods that are carefully designed and well-grounded in theory, each valuation exercise remained specific to the study site in question (e.g., specific to the species, valuation frame and survey population) and researchers employed a research design that may differ from other valuation of the same environmental good. As discussed earlier, the compiled 729 values were reported in 54 different forms (e.g., value per person per year, value per household for five years) (Appendix C).

Valuation methods have been continuously applied and developed over the past decades, but there remains some room for improvement and this includes the standardisation of how to quantify, measure, describe and report environmental values. Clough and Bealing (2018) found that NMV studies in New Zealand remain "too few and varied to infer much about the generic value of environmental improvements". They recommended that more NMV studies should be undertaken to increase the range of estimates while also developing a set of standardised valuation approaches for assessing a broad range of important environmental attributes. Such initiatives would help increase the relevance and usefulness of future NMV studies for undertaking more holistic and inclusive biosecurity risk assessments. There has also been some global and New Zealand initiatives to compile databases of NMVs and some of these are described in de Groot, Brander, and Solomonides (2020), McVittie and Hussain (2013) and Yao and Kaval (2011).

An important critique of the NMV approach revolves around its basis in Western knowledge systems, and the primacy therein of economic attributes and standards. NMV frameworks have generally operated on the assumption that all values are amenable to measurement by way of the market economy—constituting what Cole (2018) refers to as a "system of [Western] cultural projection that imposes a way of thinking about the world". The NMV of ES has helped highlight the value of various ecological functions in (market) contexts where these functions were historically not valued, were ignored in decision making and were thus not protected (TEEB, 2010; UKNEA, 2011). However, monetary valuation methods may not always adequately address other key but traditionally marginalised dimensions of environmental management and governance, including questions of fairness and equity (Spangenberg & Settele, 2010). Spangenberg and Settele (2010) note that management decisions are in the first instance political decisions (as well as moral and ethical decisions; see (Awatere, 2005)) in which the mutually agreeable solution, arrived at through a lengthy process of discussion and debate, may not be the most economically efficient solution. Methods that provide a more in-depth analysis for this particular dimension of value should be employed, for example the environmental social science method described in Gurney, Mangubhai, Fox, Kiatkoski Kim, and Agrawal (2021). These methods may include but are not limited to: (1) group or deliberative approaches; (2) subjective scaling; (3) paired comparison; and (4) multi-criteria analysis.

Used on its own, NMV may not be applicable for examining particular values and value frameworks, and their associated worldviews and ways of knowing, because of these frameworks' incongruency with compartmentalisation and/or translation into monetary units of measurement (Chan, Satterfield, & Goldstein, 2012). This is evident in the New Zealand context, where the attempt to measure one or another environmental value through economic methods belies the Māori epistemology concerning the interrelationship of all living things through the bond of whakapapa (genealogy) (Awatere, 2005; Harmsworth & Awatere, 2013). To try to deduce the economic value of the mauri of a natural resource is to remove it from the very context through which the world may be understood (Awatere, 2005). Harmsworth and Awatere (2013) further explain that Māori cultural values should not be relegated to the category of cultural or intangible services in the ES framework. Instead, Māori cultural values form the basis for all other ES, including use and non-use, tangible and intangible, and provisioning, regulating, cultural and supporting. In this case, it is inappropriate to compartmentalise Māori values in order to fit a Western lens; these values must be understood on their own terms rather than as an "appendage" to a

Western cultural framework (Harmsworth & Awatere, 2013). This adds other dimensions of values and should be examined using other more appropriate value frameworks. Alternatively, in NMV, one has the option to use a non-monetary payment vehicle (for example, willingness to spend time to volunteer or to engage with the community). Economics is the study of scarce resources which include time and other important resources. Ranking may also be used, as in the biosecurity acceptability choice experiment study by Yao, Wegner, Matthews and Grant (2021). These considerations suggest that the NMV approach should sit beside other equally important tools as one factor in a holistic decision-making process (Chan et al., 2012; Harmsworth & Awatere, 2013). NMV may be used in conjunction with qualitative methods, multi-criteria assessment, and/or other forms of deliberative decision-making that are adapted to the situation at hand. Likewise, the decision-making process should incorporate a wider and more diverse range of perspectives and worldviews to contribute to a fuller accounting of ES values. In the New Zealand case, Māori partnership in environmental management and governance matters is not only a desired outcome but a Treaty of Waitangi obligation; this partnership should be undertaken in such a way that Māori values are acknowledged as valid based on their positioning within Māori, and not Western, cultural frameworks and knowledge systems (Lyver et al., 2017; Tengö et al., 2017).

## Opportunities and way forward

As discussed above, NMV of ES values (including those non-use values estimated using stated preference approaches) can aid in developing holistic and inclusive impact risk assessments as it allows the incorporation of environmental and social values in decision making processes (Baker & Ruting, 2014). For natural resource managers, NMV can help better justify proposed biosecurity projects as well as help continue to secure on-going funding as financial, environmental and social benefits are demonstrated. Similar to Clough and Bealing (2018), we found that both in New Zealand and globally, there remains a severe lack of studies representing the broader set of biosecurity protection values in decision making.

Under the BHNSC-SO3 programme, there is an opportunity to develop a multi-disciplinary valuation approach that is co-designed with end users. This is because biosecurity risk protection values can be multifaceted and complex, thus a hybrid approach would produce a more transparent and holistic set of environmental values and the publications coming from this research would likely gain higher policy and science impacts. The BHNSC-SO3 programme consists of a core multidisciplinary team which includes biophysical modellers, social scientists, environmental economists and Māori researchers that convenes regularly with end users consisting of government and industry representatives. This set up would enable cross fertilisation of ideas leading to the co-development of a research design that can robustly quantify non-market ecosystem service values that are complementary to social, cultural and economic values.

In our literature review, we found that recent papers have combined ecological simulation models with non-market valuation methods (Daniels et al., 2017; Sheng et al., 2019) while Tobias Börger and Hattam (2017) combined choice experiment with the theory of planned behaviour approach. There is potential that we can develop a hybrid approach where we combine ecological, economic, social and potentially Te Ao Māori approaches. The combination of these research approaches will result in the quantification and/or description of a holistic set of values (which may potentially include ethical considerations and a pluralistic set of values) that can be delivered by a proposed multiyear biosecurity programme. The above would contribute to a more transparent and inclusive value-based framework to inform biosecurity risk assessment.

Most of the estimated environmental values in the literature review were expressed in willingness-to-pay in monetary form. This is the mainstream type of payment vehicle in economic valuation scenarios. There is potential that the team could develop and employ other types of payment vehicles such as willingness to spend time for volunteering, training and/or education to support a potential programme that would lower the risk of pest incursions. We have an on-going work at Scion that employed the choice experiment method where we used an acceptability ranking of biosecurity tools as our payment vehicle (Yao et al. 2021) instead of the usual willingness to pay in NZ dollars per year for five years. That study was undertaken by a research team consisting of economists and social scientists.

Combining expertise from different disciplines while accounting for the views and research needs of end-users is synergic. This would allow the BHNSC-SO3 team to build on the strengths of different valuation methods and value frameworks while also addressing the weaknesses of each method. For example, there is a debate that intrinsic value is not totally captured in the economic valuation framework. The economic valuation framework is focused more on the broader instrumental or utilitarian value and somewhat lightly touches on relational values. Social science tools can examine relational values and better illustrate and describe those values to inform decision making processes. Therefore, the two approaches can work hand-in-hand to ensure that different values, including instrumental and relational, can be captured in the valuation process. This will allow them to be quantified, described and represented in biosecurity risk assessment frameworks. Developing hybrid valuation methods like the ones discussed above is a high growth research area and is attracting increasing attention in the literature and in practice.

# Conclusions and recommendations

This literature review provides an overview of what has been undertaken in terms of the economic determination of non-market values in the context of biosecurity protection and incursion risk reducing initiatives. The literature review did not aim to compare non-market values with economic market values but to provide an overview of the different approaches to measuring the flow of ecosystem-service-related values using various non-market valuation techniques. Different pest species in different locations and biosecurity initiatives (both observed and hypothetical) and their corresponding outcome benefits to society were evaluated by the 75 studies compiled.

The values compiled in this literature review provides an overview of the studies where the wider benefits of biosecurity interventions have been quantified and compared using indicators of ES. Those indicators may be used to identify what environmental factors and related items should be considered in a holistic value-based biosecurity risk assessment framework.

1. ES values impacted by biosecurity have been found to be greater than financial values and their protection would provide significant long-term benefits that would better justify the investments in biosecurity protection initiatives.
2. Accounting for non-market environmental values in decision making would help sustain and enhance environmental quality especially those that enhance human well-being.

Since environmental values have remained ignored in decision making processes and there remains a severe lack of non-market valuation studies to support decision making, **we recommend the development a hybrid valuation method.** This will enable a more coordinated valuation of environmental values to foster a transdisciplinary approach (i.e., collaboration across the multidisciplinary researchers with co-design inputs from end users consisting of stakeholders from the government, industry, Māori and user groups). This would help address the limitations of the tool, robustly estimate multiple values to inform impact assessments, and capitalise on progress within the on-going BHNSC-SO3 programme. It would also allow other subject matter leaders (social science, Māori, and economics) to work on valuation research that is highly complementary to the environmental valuation research. There is indeed a great opportunity for the programme team to develop a hybrid and transparent approach that would identify and assess a holistic and scalable set of values that can be used in biosecurity risk assessment for Aotearoa.

# Acknowledgements

We thank John Kean and Christine Reed, co-leaders of the Biological Heritage National Science Challenge Strategic Outcome 3, for providing our team the opportunity to work together on this project. We thank Peter Tait of Lincoln University for his help in providing additional references for this literature review. We would also like to thank the three anonymous reviewers who provided valuable comments on the earlier draft version of the report.

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# Appendix A

## Multiple values provided by Whakarewarewa forest in Rotorua, New Zealand

The 2427-ha Whakarewarewa forest in Rotorua provides multiple benefits to society. About 43% of the forest is planted in exotic tree species (mainly *Pinus radiata*) consisting of a mosaic of forestry plots of different ages allowing the establishment, growing, harvesting and sale of logs to occur continuously across the forestry estate every year. Some harvested logs are exported overseas while others are mostly sawn into lumber at the local mill. Therefore, forestry operations contribute to national and regional economic development through production, processing and sale of timber with financial values that are reflected in New Zealand's and in the region's gross domestic product (GDP). About 180 kilometres of mountain biking trails and a number of walking and horse riding tracks cut across both production and conservation sections of the forest (Redwoods I-Site & Visitor Information Centre, 2021; RideNZ, 2021). Public recreational access has also been estimated to provide millions of dollars to the regional GDP through the revenues generated by mountain biking shops, accommodation and restaurants. Mountain biking tourism in the forest generates between $29 and $47 million annually in business revenues and employs about 210 full-time equivalent jobs in the Rotorua district (Michael Connell and Associates, 2018). In addition to the material benefits that are observed in market transactions, Whakarewarewa also provides non-market values and these include sequestration of carbon dioxide, recreational benefits to the public, provision of habitats for native birds (i.e., kārearea or NZ bush falcon) and native vegetation that provides landscape values (Dhakal et al., 2012; Richard Yao et al., 2013). The non-market recreational use value of recreational mountain biking and walking in Whakarewarewa forest was estimated using the travel cost method and it was found that the aggregated recreational use value can be more than twice the annual timber revenue (Dhakal et al., 2012). In undertaking a biosecurity risk assessment for Whakarewarewa, the market benefits of logs as well as the non-market environmental values and other values need to be accounted for to support sustainable and holistic planning and decision-making processes.

# Appendix B

## Description of the 75 studies used in the literature review

| ID | Citation | Indicator | Country | Year published | Publication type | Source |
|---|---|---|---|---|---|---|
| 1 | Adams et al. 2011 | Recreation | US | 2011 | Article | Scopus |
| 2 | Adams et al. 2020 | Environmental protection | US | 2020 | Article | Scopus |
| 3 | Arnberger et al. 2017 | Recreation | US | 2017 | Article | Scopus |
| 4 | Bekele et al. 2018 | Dryland ecosystem services | Ethiopia | 2018 | Article | Scopus |
| 5 | Bell et al. 2008 | Biodiversity; recreation | New Zealand | 2008 | Conference paper | Experts |
| 6 | Bell et al. 2009 | Biodiversity | New Zealand | 2009 | Conference paper | Experts |
| 7 | Beville et al. 2012 | Recreation | New Zealand | 2012 | Article | Scopus |
| 8 | Borger et al. 2014 | Conservation | UK | 2014 | Article | Scopus |
| 9 | Brown and Daigneault 2014 | Social/economic impacts | Fiji | 2014 | Article | Scopus |
| 10 | Burnett et al. 2007 | Biodiversity; hydrology | US | 2007 | Article | Scopus |
| 11 | Chan-Halbrendt et al. 2007 | Biodiversity; soil erosion; invasive species spread | US | 2007 | Article | Scopus |
| 12 | Chan-Halbrendt et al. 2010 | Biodiversity; soil erosion; invasive species spread | US | 2010 | Article | Scopus |
| 13 | Chang et al. 2011 | Recreation; environmental protection | Canada | 2011 | Article | Experts |
| 14 | Chang et al. 2012 | Recreation; environmental protection | Canada | 2012 | Article | Experts |
| 15 | Cooke et al. 2010 | Environmental protection | Australia | 2010 | Article | Scopus |
| 16 | Daniels et al. 2017 | Biodiversity; biological pest control | Belgium | 2017 | Article | Scopus |
| 17 | de Lange et al. 2013 | Forage provisioning | South Africa | 2013 | Article | Scopus |
| 18 | Drake and Jones 2017 | Recreation; non-use | UK | 2017 | Article | Scopus |
| 19 | Du Preez and Hoskin 2010 | Recreation | South Africa | 2010 | Working paper | Scopus |
| 20 | Eiswerth et al. 2000 | Recreation | US | 2000 | Article | Scopus |
| 21 | Engeman et al. 2003 | Habitat | US | 2003 | Article | Scopus |
| 22 | Fleischer et al. 2013 | Aesthetic; landscape | Israel | 2013 | Article | Scopus |
| 23 | Garc´ıa-Llorente et al. 2011 | Conservation; biodiversity | Spain | 2011 | Article | Scopus |
| 24 | Gong et al. 2008 | Biodiversity | Australia | 2008 | Conference paper | Experts |
| 25 | Gren et al. 2018 | Nutrient storage; nutrient cleaning | Selected European countries | 2018 | Article | Scopus |
| 26 | Haight et al. 2011 | Landscape; aesthetic; human health | US | 2011 | Article | Experts |
| 27 | Holmes et al. 2010 | Landscape; aesthetic | US | 2010 | Article | Scopus |
| 28 | Horsch and Lewis 2009 | Water-based recreation and aesthetic; environmental quality | US | 2009 | Article | Scopus |
| 29 | Iranah et al. 2018 | Conservation | Mauritius | 2018 | Article | Scopus |
| 30 | Jetter and Paine 2004 | Landscape and aesthetic | US | 2004 | Article | Experts |
| 31 | Jones 2017 | Human well-being | US | 2017 | Article | Scopus |
| 32 | Jones 2018 | Human health | US | 2018 | Article | Scopus |
| 33 | Jones 2019 | Human health | US | 2019 | Article | Scopus |
| 34 | Julia´ et al. 2007 | Agriculture; wildlife support; water quality | US | 2007 | Article | Scopus |
| 35 | Junge et al. 2019 | Ecological; economic | Switzerland | 2019 | Article | Scopus |
| 36 | Kerr and Sharp 2007 | Wilding conifers control | New Zealand | 2007 | Report | Experts |
| 37 | Kerr and Sharp 2008 | Biodiversity; recreation | New Zealand | 2008 | Report | Experts |
| 38 | Kovacs et al. 2010 | Landscape; aesthetic | US | 2010 | Article | Experts |
| 39 | Kovacs et al. 2011 | Landscape; aesthetic | US | 2011 | Article | Scopus |

| ID | Citation | Indicator | Country | Year published | Publication type | Source |
|---|---|---|---|---|---|---|
| 40 | Lauber et al. 2020 | Recreation | US | 2020 | Article | Scopus |
| 41 | Lehrer et al. 2010 | Biodiversity; conservation | Israel | 2011 | Article | Scopus |
| 42 | Lewis et al. 2015 | Recreation | US | 2015 | Article | Scopus |
| 43 | Liu and Tien 2019 | Recreation; biodiversity; human health | Taiwan | 2019 | Article | Scopus |
| 44 | Mazur et al. 2018 | Protection of native species, coastlines and adjacent waters | Australia | 2018 | Report | Experts |
| 45 | McIntosh et al. 2010 | Freshwater ecosystem services | US | 2010 | Article | Scopus |
| 46 | Mejía and Brandt 2015 | Recreation; environmental protection | Ecuador | 2015 | Article | Scopus |
| 47 | Meldrum et al. 2013 | Environmental protection; recreation | US | 2013 | Article | Scopus |
| 48 | Mwebaze et al. 2010 | Biodiversity; environmental protection | Seychelles | 2010 | Article | Scopus |
| 49 | Nikodinoska et al. 2014 | Recreation; environmental protection | South Africa | 2014 | Article | Scopus |
| 50 | Nunes et al. 2015 | Recreation | Spain | 2015 | Article | Scopus |
| 51 | Nunes and van den Bergh 2004 | Beach recreation; environmental protection | Netherlands | 2004 | Article | Scopus |
| 52 | Ofori and Rouleau 2020 | Environmental protection | Ghana | 2020 | Article | Scopus |
| 53 | Oh et al. 2018 | Environment; economy; human health | US | 2018 | Article | Scopus |
| 54 | Olaussen and Liu 2011 | Recreation | Norway | 2011 | Article | Scopus |
| 55 | Pakalniete et al. 2017 | Biodiversity; recreation; water quality | Latvia | 2017 | Article | Scopus |
| 56 | Peled et al. 2020 | Marine ecosystem services | Israel | 2020 | Article | Scopus |
| 57 | Provencher et al. 2012 | Recreation; aesthetic | US | 2012 | Article | Scopus |
| 58 | Radics et al. 2018 | Protection of eucalyptus forests | New Zealand | 2017 | Report | Experts |
| 59 | Rai and Scarborough 2013 | Forest ecosystem services | Nepal | 2013 | Article | Scopus |
| 60 | Raynor and Phaneuf 2020 | Recreation | US | 2020 | Article | Scopus |
| 61 | Rolfe and Windle 2014 | Health; lifestyle; environmental | Australia | 2014 | Article | Scopus |
| 62 | Schwoerer et al. 2020 | Recreation | US | 2020 | Article | Scopus |
| 63 | Sheremet et al. 2017 | Forest ecosystem services | UK | 2017 | Article | Scopus |
| 64 | Subroy et al. 2018 | Conservation | Australia | 2018 | Article | Scopus |
| 65 | Tait and Rutherford 2017 | Biodiversity | New Zealand | 2017 | Technical paper | Experts |
| 66 | Tait et al. 2017 | Conservation; biodiversity | New Zealand | 2017 | Article | Scopus |
| 67 | Turpie et al. 2003 | Biodiversity; recreation | South Africa | 2003 | Article | Scopus |
| 68 | van Beukering et al. 2008 | Forest ecosystem services | UK | 2008 | Report | Scopus |
| 69 | Van Oijstaeijen et al. 2020 | Lake ecosystem services | Ethiopia | 2020 | Article | Scopus |
| 70 | Velarde et al. 2015 | Environmental protection | New Zealand | 2015 | Article | Experts |
| 71 | Wainger et al. 2018 | Recreation; water supply | US | 2018 | Article | Scopus |
| 72 | Weber and Stewart 2009 | Conservation; restoration | US | 2009 | Article | Scopus |
| 73 | Yao et al. 2019 | Conservation of iconic species and predator control | New Zealand | 2019 | Article | Experts |
| 74 | Zander 2013 | Recreation, biodiversity and carbon sequestration | Australia | 2013 | Article | Experts |
| 75 | Zhang and Boyle 2010 | Water-based recreation and aesthetic | US | 2010 | Article | Scopus |

# Appendix C

## Summary of units used to report measures of environmental value (total count = 729)

| ID | Value unit | Count | ID | Value unit | Count |
|---|---|---|---|---|---|
| 1 | All users/year | 109 | 28 | City/year | 5 |
| 2 | Household/year for 5 years | 65 | 29 | Household/5 years | 5 |
| 3 | Household/year | 59 | 30 | Neighbourhood/year | 5 |
| 4 | State or province/>5 years | 50 | 31 | Property/year | 5 |
| 5 | Person/year | 47 | 32 | Sector/year | 4 |
| 6 | All residents/year | 36 | 33 | Per household | 4 |
| 7 | County/>5 years | 35 | 34 | Person/day | 4 |
| 8 | Person/trip | 25 | 35 | Person/tour | 4 |
| 9 | State or province/year | 22 | 36 | Per year | 3 |
| 10 | All households/year | 19 | 37 | Person/month | 3 |
| 11 | Country/>5 years | 19 | 38 | All households | 3 |
| 12 | Person/visit | 17 | 39 | Household/month for 1 year | 3 |
| 13 | Per hectare | 17 | 40 | City/five years | 2 |
| 14 | Hectare/year | 15 | 41 | Neighbourhood/5 years | 2 |
| 15 | County/year | 15 | 42 | Region/5 years | 2 |
| 16 | Country/year | 14 | 43 | Country/5 years | 2 |
| 17 | Region/year | 13 | 44 | Person/year for 7 years | 2 |
| 18 | Household/year for 10 years | 12 | 45 | Million gallons lost/year | 2 |
| 19 | Per property | 11 | 46 | User/visit | 2 |
| 20 | All trips/year | 10 | 47 | Household/month | 1 |
| 21 | User/year | 9 | 48 | Household/week | 1 |
| 22 | Per trip | 8 | 49 | Household/>5 years | 1 |
| 23 | Rank | 7 | 50 | User/trip | 1 |
| 24 | Region/>5 years | 7 | 51 | User/day | 1 |
| 25 | Person/>5 years | 7 | 52 | Per person | 1 |
| 26 | Non-user/year | 6 | 53 | All properties/year | 1 |
| 27 | All households/5 years | 5 | 54 | All land values/year | 1 |