

AN ECOLOGICAL RISK ASSESSMENT OF THE ESTABLISHMENT OF THE ASIAN
GIANT HORNET (*VESPA MANDARINIA*) IN THE PACIFIC NORTHWEST

by

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iii
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TABLE OF CONTENTS

1. INTRODUCTION.....1

2. PROBLEM FORMULATION.....3

3. STRESSOR DESCRIPTION.....4

 Species.....4

 Life cycle and nesting biology.....4

 Habitat preferences and ecosystem relationships.....5

 Feeding and predation strategies.....6

4. Introduction pathways: Natural and human-mediated.....7

 Natural introduction.....7

 Human-mediated introduction.....8

5. EFFECTS ASSESSMENT.....10

 Potential effects in the Pacific Northwest.....12

6. EXPOSURE ASSESSMENT.....13

 Plant Hardiness Zones and habitat suitability.....14

 ‘Greenspace’ habitat suitability.....16

Honey bee colony density and distribution in relation to Plant Hardiness

Zones.....	18
7. RISK CHARACTERIZATION.....	21
8. UNCERTAINTY ANALYSIS.....	26
9. GOING FORWARD.....	28
10. REFERENCES CITED.....	30

LIST OF TABLES

1. Risk rating table for *V. mandarinia* establishment in Washington State.....22
2. Risk rating table for *V. mandarinia* establishment in Oregon.....24

LIST OF FIGURES

1. Major freight and cargo ports in the Pacific Northwest.....9

2. Plant Hardiness Zone map of Washington.....15

3. Plant Hardiness Zone map of Oregon.....16

4. Forest biomass in the Pacific Northwest with apiary distribution.....17

5. Total honey bee hives by county in Washington State.....19

6. Total honey bee hives by county in Oregon.....20

7. Overall risk rating score map by county in the Pacific Northwest.....25

ABSTRACT

The recent introduction of the Asian giant hornet (*Vespa mandarinia*) in the United States in late 2019 has raised concerns about the establishment of the insect in the Pacific Northwest, and its potential deleterious effects to honey bees and their pollination services in the region. Therefore, I conducted a risk assessment to estimate the risk of establishment of *V. mandarinia* in Washington and Oregon on a county by county basis. To assess these risks, my assessment used the risk assessment framework put forth by the U.S. National Research Council. The risk assessment relied on the biological requirements and ecological relationships of *V. mandarinia* in the environments of the Pacific Northwest. I based the risk characterization on climate and habitat suitability estimates for *V. mandarinia* queens to overwinter and colonize nests, density and distribution of apiaries, and locations of major human-mediated introduction pathways that may increase the risk of establishment of the hornet in the counties of Washington and Oregon. My results suggest that 70 of the 75 counties in the region could be at medium to high risk of establishment by the hornet. Many of the western counties of both Washington and Oregon were estimated to be at the highest risk of establishment, mainly due to their suitable climate for queens to overwinter, dense forest biomass for nest colonization, and proximity to major port and freight hubs in the region. Considering its negative effects, these counties should be prioritized in ongoing monitoring and eradication efforts of the insect.

INTRODUCTION

Risk assessments are often used to frame the potential risks that invasive species pose to an ecosystem, economic sectors and industry, and human health and safety. The recent introduction of the Asian giant hornet (*Vespa mandarinia*) is one such invasive species which poses risks to each of those categories in the U.S. *Vespa mandarinia* is the largest species of hornet in the world and is a member of the genus *Vespa*, a primary predator of honey bees (Smith-Pardo, et al. 2020). The insect was first detected within the U.S. in late 2019 in Whatcom County in northern Washington State, and again in May 2020 in the same county, indicating the possibility of wider spread establishment than just a chance introduction and detection. Further positive confirmed sightings since May 2020 have prompted federal and state agricultural officials to initiate eradication programs for the pest due to the insect's propensity to decimate honey bee populations and impact human safety due to its stings, making the insect a threat to the ecosystems, agricultural sectors, and human health and safety within the surrounding areas of their nesting sites.

With these risks in mind, it is critical to properly frame them to be able to effectively mitigate these hazards to avoid deleterious results to the environment and economy. Therefore, my paper is a qualitative risk assessment of the establishment of *V. mandarinia* in the Pacific Northwest, focusing on Washington and Oregon

Biological invasions are ecologically and economically damaging phenomena which occur in environments around the world. The introduction and establishment of non-native species disrupts native flora and fauna and their ecosystems, and concomitantly often causes

deleterious consequences to a host of economic sectors and at times even public health and safety. To characterize these consequences, risk assessments are regularly developed to frame the problem and ultimately to confer the degree of risk to regulatory agencies and industry pertaining to the establishment of the particular invading species. The type of risk assessment used is ultimately dependent on the data available for a particular stressor. In cases of a new introduction of an invasive species, where an invasion is in its early onset, qualitative based risk assessments are often employed as a direct result of a lack of quantitative and distribution data for the biological invader in question (Soliman et al. 2014).

Regardless of the type of risk assessment used, each follows the same step-based framework put forth by the U.S. National Research Council (NRC, 1983). The process begins with developing the ‘problem formulation’ which has the goal of informing the overall scope of the risk assessment and the stressor which is being assessed. Next, a ‘stressor description’ aims to describe exactly that — a full accounting of the stressor and the particular effects produced by that stressor. Moreover, the stressor description lays out and assesses the ‘effects’ the stressor may incur upon its environment, whether that be in ecological, economic, or human health and safety terms.

With the ‘effects’ of the stressor in mind, the subsequent step within the risk assessment framework is to assess the ‘effects’ and ‘exposure’ brought on by the stressor to its environment. The effects and exposure assessment applies and synthesizes data and takes into account the impacts or potential consequences that the stressor produces. With the problem formulation determined, the particular stressor described, and the effects and exposure of the stressor assessed, the culmination of the risk assessment is to characterize and communicate the degree of

risk a particular stressor incurs to its surrounding environment. The risk characterization in qualitative risk assessments is often based on an appropriate risk ranking system or scoring system, often informed by expert opinion, and relies on the relationships between the particular stressor and the ecosystems it inhabits (Soliman et al. 2014). Once the risks of the particular stressor have been summarily described and characterized, this information can then be passed to the appropriate regulatory officials, industry, or public health and safety agency to help inform management and decision making with regard to handling the stressor and ultimately mitigate its risks.

PROBLEM FORMULATION

The first step of any risk assessment begins with the initial problem formulation. The problem formulation sets the stage in terms of the scope, steps, and methodologies of the risk assessment, delineating the ‘stressor’ and its ‘effects’ at its center of focus. In the case of my risk assessment, that stressor is the establishment of *V. mandarinia* in the U.S. Pacific Northwest and its deleterious effects on the region’s ecosystems and economy. Accordingly, my risk assessment will begin with a complete accounting of the biological and ecological characteristics of the stressor, *V. mandarinia*. Additionally, the stressor description will also classify the effect that *V. mandarinia* has on its surrounding ecosystems, focusing on risks to honey bee populations and apiaries. I will analyze the extent of these effects to assess the degree of exposure to these risks in the effects and exposure assessment section of the risk assessment, which will primarily analyze habitat suitability for the insect, factors influencing introduction, and risk to honey bee

populations. The final section of my risk assessment will draw from the findings of the previous steps, and ultimately score and characterize the risks of the establishment of the *V. mandarinia* in the Pacific Northwest.

STRESSOR DESCRIPTION

Species

The Asian giant hornet (*Vespa mandarinia* Smith, 1852) is prevalent throughout Asia, with its range extending from mainland Asia into Taiwan, Japan, and South Korea (Archer, 1995). The insect is in the *Vespidae* family, within the order *Hymenoptera*. *Vespa mandarinia* is the largest known species of hornet in the world, ranging from 38-50 mm in length. Although it has a yellow and black abdomen common to many other wasp species, its orange head (Lee, 2010), and largely exaggerated facial features make it easily distinguishable from its close relatives (Matsuura and Sakagami, 1973).

Life cycle and nesting biology

Vespa mandarinia is a species of social hornet that has two separate castes, the queens and workers, each fulfilling duties integral to the success of the colony (Archer, 1995). The life cycle of *V. mandarinia* begins with a solitary queen initiating nest foundation after overwintering in a self-excavated cavity in soft ground surface, burrow, or other primarily ground-based substrate. Nest formation takes place over a number of weeks in the late spring. During this period, the queen builds and develops the nest, prepares to lay eggs, and feeds on arthropods and plant-derived sap (Archer, 1995). The summer brings the beginnings of the actual colony, as the queen takes care of her brood and workers eventually begin to emerge. Once the colony has

enough workers, the duties of the colony are transferred solely to the workers, while the queen remains in the confines of the nest and continues to lay eggs (Matsuura and Sakagami, 1973).

With early fall comes mating season for *V. mandarinia* colonies, with both new queens and reproductive males emerging (Archer, 1995) (Matsuura and Sakagami, 1973). Males leave the nest before the queens to forage and to wait to mate with the newly emerging queens at the entrance of the nesting site (Matsuura, 1984). The activity of the colony gradually decreases in the late fall before ceasing in the early winter, when queens will then need to find a site in which to overwinter (Archer, 1995). Maturity from egg to adult is approximately 40 days (Matsurra, 1984) and the colony cycle lasts approximately six months, with the males and workers living for approximately 3 weeks, while new queens live as long as 12 months when taking their overwintering period into account (Archer, 1995).

The nests are assembled primarily in pre-existing ground-based cavities, versus above ground nest sites. The nests can be fairly complex and vary in size, with the average containing a few thousand individual cells made from foraged wood-based fibers. The larvae mature in the cell (Matsuura and Yamane, 1990). Archer (1995) reported a nest containing approximately 6,000 cells. Although the average nest can contain a few thousand separate cells, the actual colony size produced from those cells is usually much smaller. The variable cell count of each nest makes it difficult to estimate the size of the colony that will be produced from those cells. Despite this, Archer (1995) observed that a colony produced an average of approximately 200 males and 200 queens in a given cycle in addition to thousands of workers.

Habitat preferences and ecosystem relationships

Like other species, *V. mandarinia* has specific habitat preferences and ecological niche requirements which ultimately inform relationships between other species in its surrounding environment and ecosystem. In its native range in parts of mainland and eastern Asia, its distribution has been primarily linked to certain abiotic and biotic factors. Chiefly, it seems to be sensitive to high temperatures and prefers more temperate climates, areas of low elevation and high amounts of precipitation for its nesting site (Alainz et al. 2020, Kim et al. 2020, Zhu et al. 2020). However, there are reports of *V. mandarinia* attacking honeybee colonies at high altitudes, such as in the Himalayan ranges (Batra, 1996). Furthermore, queens prefer ‘greenspaces’ and environments, such as forested areas, parks, agricultural zones, and green herbaceous environments (Kim et al. 2020, Alainz et al. 2020). This finding raises concerns about the risks to wild and cultivated bee populations that are in these environments. In addition, nest colonization within urban greenspaces has the potential to result in human conflicts with *V. mandarinia*, which is a risk to human health and safety. Liu et al. (2016) reported that in only a three month period (July-October when the species is typically active), 42 people died and approximately 1,700 people were injured from suffering multiple stings in China’s Shaanxi Province.

Feeding and predation strategies

Once *V. mandarinia* has occupied its new environment after initial nest colonization, it must feed and forage. The hornet has a number of food sources, most of which are located within a few kilometers of its nesting site (Matsuura and Yamane, 1990), although it is a strong flyer and has been observed foraging nearly 5 km from its nesting site (Matsuura and Sakagami, 1973).

Although the species is most known for its predation on social insects, it has also been observed to feed on sap from a number of different plant species. In Japan, Matsuura (1984) documented it feeding on a number *Quercus* (oak) species as well as on fruiting tree species. Feeding on the sap of both trees and fruit can result in crop damage.

In addition to feeding on plants, *V. mandarinia* is well known to aggressively prey on insect species. The insect attacks beetles, spiders, other social wasp species, but is most well-known for its mass attacks on honey bee species and their colonies. (Matsuura and Yamane, 1990, Matsuura, 1984). *Vespa mandarina*'s propensity to hunt honey bees has caused issues worldwide (Matsuura and Sakagami, 1973), especially in instances where it has become established and local honey bee populations have not had the chance to adapt to its attacks.

INTRODUCTION PATHWAYS: NATURAL AND HUMAN-MEDIATED

Natural introduction

Introduction of nonnative species to new territories through natural dispersal such as flying or foraging is unlikely to occur over large geographic distances. However, this does not exclude the possibility of a nonnative species further broadening its range once it has been introduced into a new environment. In the case of *V. mandarinia*, it has the ability to fly and forage as far as nearly 5 km from its nesting site, though it typically sticks to a much smaller radius of approximately 2 km from its nest (Matsuura and Sakagami, 1973). In addition, because amino acids contained in larval saliva that are secreted to adults during nutritional exchange, this form of trophallaxis is responsible for giving adults the energy to fly at speeds of approximately 29 km per hour, covering flight distances of nearly 100 km per day during hunting and foraging

(Abe et al, 1995).

Considering queens alone are ultimately responsible for establishing new colonies, and mostly forgo hunting and foraging responsibilities once workers are produced, the actual burden of establishing new colonies in new territories rests with the new queens emerging at the end of the colony's yearly cycle. However, without adequate data on queen dispersal distances at this point in their life cycle, it is difficult to know how much natural dispersal plays in range expansion into new territories.

Human-mediated introduction

Unlike natural methods of nonnative species introduction into new environments, human-mediated introduction is considered the leading cause of nonnative biological invasions, not only in the U.S., but also around the world (Vitousek et al. 1997). This is a result of extensive land transformations producing favorable conditions for invasion, and accidental introductions due to international export and import commercial trade (Vitousek et al 1997). In the case of *V. mandarina* being introduced to the U.S. in northern Washington, human-mediated introduction through economic trade is the likely reason considering the species was found close to the U.S./Canadian border near ports of entry, and that the region serves as a destination for commercial trade commodities from Asia (Wilson et al. 2020) (Figure 1). This is supported by the captures of *V. mandarina* in both Vancouver, British Columbia and Washington that were found to originate from two separate lineages (Wilson et al. 2020). The individual captured in British Columbia had DNA from a lineage in Yamaguchi, Japan, while the captured specimen in

Washington had DNA linked to a maternal lineage in Chungcheonuk-do, South Korea. Both these introductions in British Columbia and Washington were likely from separate mated queens, although the data could not determine whether these specimens were from the same populations or were introduced at the same time (Wilson et al. 2020). Despite this, the data seem to substantiate the role that human-mediated transport through economic trade has played in the introduction of *V. mandarina* to North America and the Pacific Northwest.

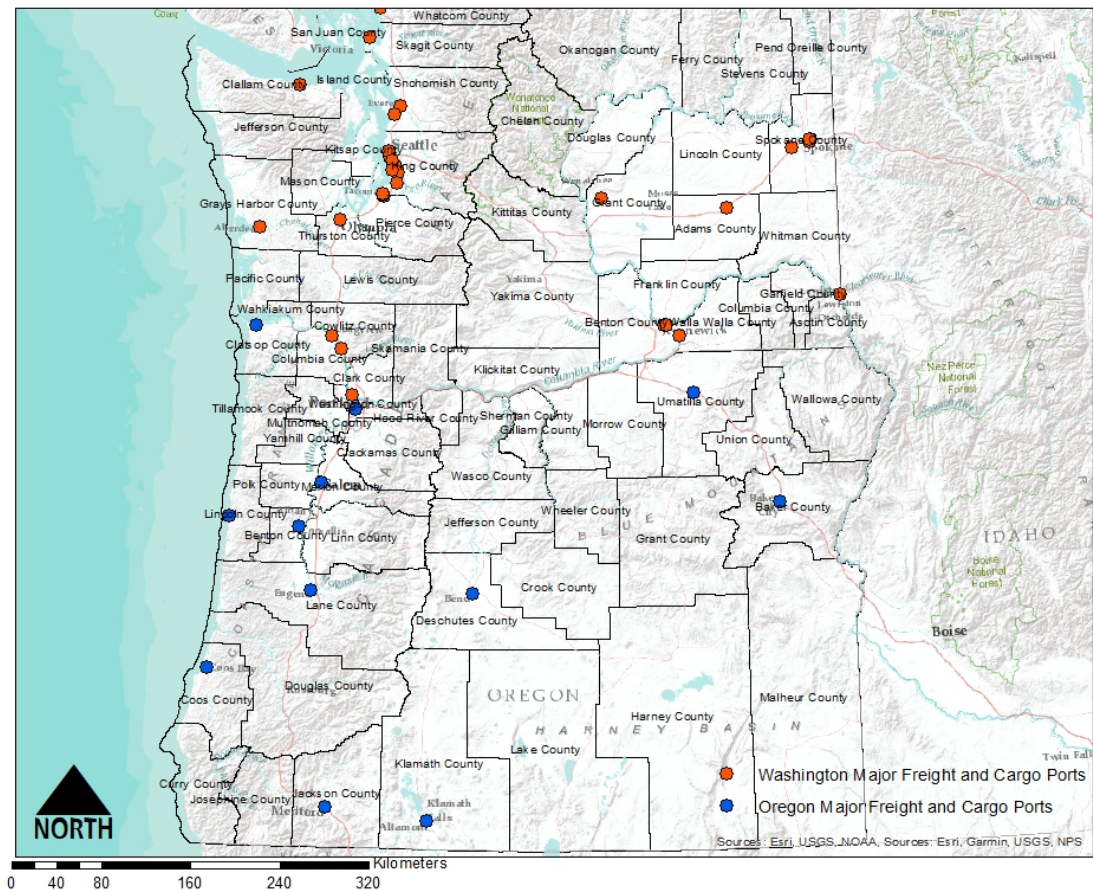


Figure 1: Major freight and cargo ports in the Pacific Northwest. The recent introduction of *V. mandarina* in North America is thought to have resulted from economic trade activities between the U.S. and Asia.

Beyond global economic trade, cultural pursuits may serve as potential pathways for the introduction of *V. mandarinia*. The species is considered a delicacy in its endemic ranges in Asia, and its pupae are consumed as food in multiple dishes. Adults are added to liquor-based drinks (New York Times, 2020). Obviously, adult specimens once added to alcoholic drinks no longer serve as a pest risk, but the transportation of the insect at any life stage where it is still living could inadvertently result in establishment if it were to escape, mature, and colonize a new nesting site. Most ports of entry within the U.S. have safeguarding and inspection measures in place to prevent the importation of live insects and foreign species in cases like this. However, a 100% interception rate is highly unlikely, so the transportation of the insect for cultural purposes must be viewed as a viable potential pathway for its introduction to nonnative regions of the U.S.

EFFECTS ASSESSMENT

The effects assessment in my risk assessment relies on *V. mandarinia* queens surviving their overwintering period and successfully initiating a new nest and establishing a colony, potentially causing negative effects to environments in the Pacific Northwest. Those potential deleterious effects occur primarily through feeding and predation strategies of the colony that result in crop damage and attacks on honey bee populations which can thereby impact pollination services.

There are distinct phases that *V. mandarinia* exhibit to attack a honeybee colony. The first phase begins with a solitary scout chemically marking a bee colony or hive by rubbing her terminal gastrite sternite directly on the targeted hive to signal to the rest of the colony of the availability of a source of food (Ono et al. 1995). Once the chemical pheromone has alerted other

members of the colony, they will gather en masse and kill the adults in the hive (Matsuura, 1984, Ono et al. 1995).

Honey bee species that have coevolved with *V. mandarinia* in their native ranges have the ability to defend themselves against attack by alerting nestmates of incoming attack using chemical cues (Fujiwara et al. 2018). They further use a defense mechanism termed a ‘hot defensive bee ball’ in which hundreds of bees swarm a single hornet and generate enough heat and carbon dioxide around the attacker to kill it (Sugaharo and Sakamoto, 2009). Ono et al. (1995) observed through thermal imagery, that the hot defensive bee ball was more than 47 °C (116 ° F) .

Once a honey bee colony’s defenses are largely overcome, *V. mandarinia* begins its occupation phase and feeds on the colony’s brood for several days (Ono et al. 1995). For honey bee species that have not coevolved with *V. mandarinia*, such as *A. mellifera*, that only have less effective stingers as a defense (Ugajin et al. 2012), complete annihilation of the colony is a likely outcome when attacked en masse by the hornet, termed the ‘slaughter’ phase (Matsuura and Sakagami, 1973, Matsuura 1988). The slaughter phase involves mass attack in which the hornets can quickly dispatch an entire colony, mostly through decapitation using their mandibles. The slaughter event lasts between one and six hours and can result in the deaths of thousands of bees or entire colonies, in which the decapitated bees are often left in massive piles inside the hive (Matsuura, 1984, Matsuura and Yamane, 1990). The occupation and slaughter phase make the hornet a significant risk to vulnerable non-coevolved bee species. Should *V. mandarinia* become established in ecosystems outside its endemic range, wild bee colonies and apiaries may suffer

extremely heavy losses resulting in substantial economic consequences to apiarists and the pollination services provided by wild bee and cultivated honey bees to hundreds of agricultural crops and plant species.

One species of honey bee that may be at potential risk from *V. mandarinia* attack is the European honey bee (*Apis mellifera*). *A. mellifera* is a critically important pollinator around the world. The honey bee pollinates hundreds of crop species within the U.S. Honey bees are the foremost insect pollinators, and constitute an estimated economic benefit of nearly \$12 billion, or roughly 80% of the total pollination value in the U.S. (Choi and Kwan, 2012).

Potential effects in the Pacific Northwest

The Pacific Northwest (primarily Washington and Oregon) is the nation's leader in specialty crops including various varieties of fruits, nuts, and berries, with a total economic value of \$4 billion annually (Houston et al. 2018). Considering that the majority of these crops are likely dependent on the pollination services provided by *A. mellifera*, the establishment and naturalization of *V. mandarinia* in the Pacific Northwest could pose high risks for agricultural producers. Beyond agricultural crop varieties, apiculture is also an agricultural sector at risk from the establishment of *V. mandarinia* in the Pacific Northwest. Furthermore, a recent survey of total honey bee colonies within the two states revealed that in June 2020 Washington State had an estimated 114,000 honeybee colonies, while Oregon had an estimated 95,000 (USDA-NASS 2020).

Beyond the potential risks *V. mandarinia* poses to agricultural and apicultural sectors, the insect also poses a risk to health and human safety. The U. S. Census Bureau estimated a

population of more than 7.5 million residents in Washington and 4.2 million residents in Oregon in 2019 (U.S. Census Bureau 2019). Although it is statistically unlikely that even a small percentage of those populations would ever interact with *V. mandarinia*, the hornet kills dozens of people per year on average in Japan and causes sting-related injuries to thousands more (New York Times, 2020).

EXPOSURE ASSESSMENT

The exposure assessment phase of any risk assessment involves drawing upon information from the stressor description and effects assessment and applies relevant data to the environment or ecosystems in question for the purposes of analysis to estimate the degree of risk, impacts, or potential consequences that the stressor may have in those environments.

Accordingly, drawing from my stressor description and effects assessment of *V. mandarinia*, my exposure assessment will rely on combining its ecology and comparing it to the ecosystems and environments of the Pacific Northwest. My analysis will primarily focus on regions that match *V. mandarinia*'s habitat suitability requirements and the presence and density of honey bee colonies. Suitable habitat for *V. mandarinia* will be based on minimum and maximum temperatures using Plant Hardiness Zone Maps of Washington and Oregon and comparing them to the climate in its native ranges in Asia. This is because minimum and maximum temperatures have been cited as necessary abiotic factors critical to the establishment of viable insect populations (Zhu et al. 2020). Therefore, this serves as a good predictor of whether *V. mandarinia* queens would be able to survive their overwintering period.

Plant Hardiness Zones and habitat suitability

The U.S. is divided into 13 separate Plant Hardiness zones across 10 °F differences, which are based upon minimum winter temperatures. These zones are further classified into two separate zones (A or B) by 5 °F differences. Washington's Plant Hardiness Zones range from 4A (-34 to -31 °C or -30 to -25 °F) to 9A (-6 to -3.8 °C or 20 to 25 °F). Oregon shares similar zone ratings, which ranges from 4B (-31 to 28.8 °C or -25 to -20 °F) to 9B (-3.8 to -1.11 °C or 25 to 30 °F) (USDA Agricultural Research Service 2020).

Vespa mandarinia's native ranges in Eastern and Southeast Asia include Plant Hardiness Zones of 3A-13B (Magarey et al. 2008). However, without thorough and up-to-date distribution data of the insect within those regions or within the Pacific Northwest it is difficult to pinpoint the exact Plant Hardiness Zones that the insect favors. However, it appears that the native range generally falls within the upper classification zones from 6-13 thereby favoring warmer climates. However, this is most likely a highly generalized estimate (Magarey et al. 2008).

Consequently, there is overlap with Plant Hardiness Zones between *V. mandarinia*'s natural range and areas in Washington and Oregon, primarily in the western and coastal regions of each state, but also in some inland regions as well (Figures 2 & 3). Thus, there is appreciable risk that queens may be able to survive their overwintering period within these regions.

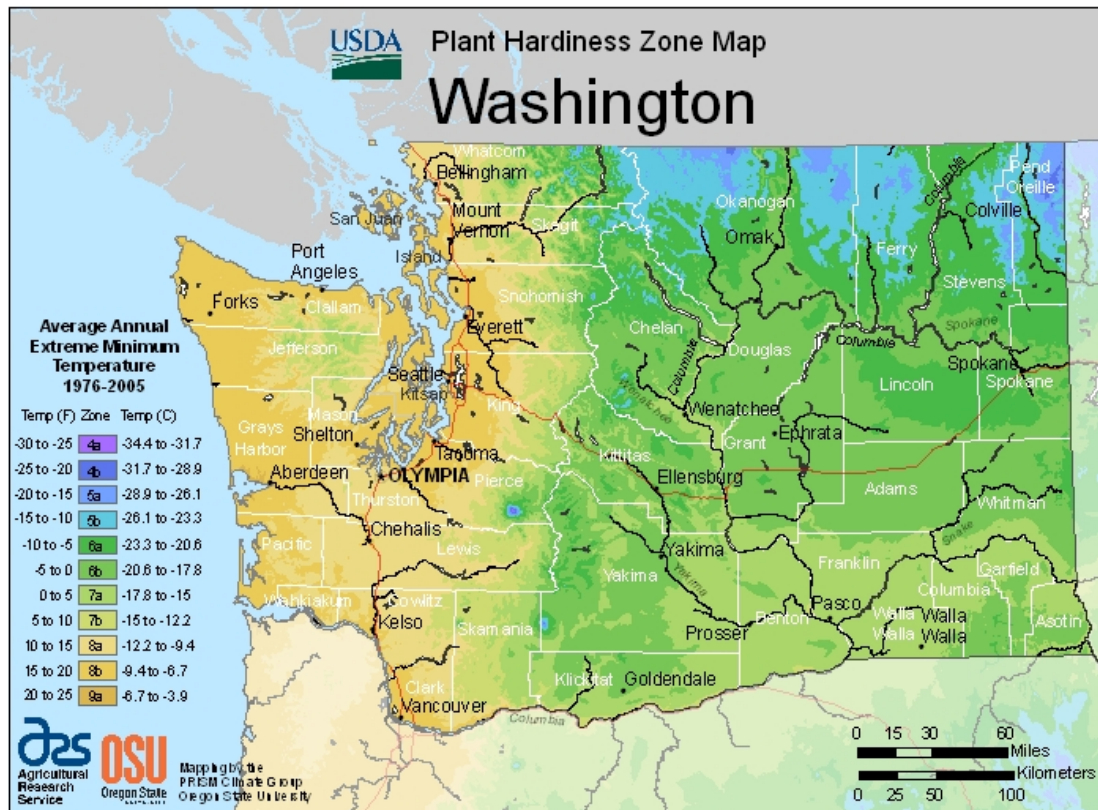


Figure 2: Plant Hardiness Zone (PHZ) Map of Washington State. PHZs are based on the average minimum winter temperature across a 30 year time frame for a region and are used to help growers determine which plants may grow best depending on the zone they inhabit. This risk assessment used PHZs to determine suitable habitat where *Vespa mandarinia* may overwinter. Washington PHZs shares some of the same PHZs which are present in *V. mandarinia*'s native ranges. These zones include 6A-9A, which include the majority of Washington State and its apiaries, indicating suitable habitat range overlap for *V. mandarinia* to overwinter in and predate on honey bee populations. (Source: USDA Agricultural Research Service, 2020)

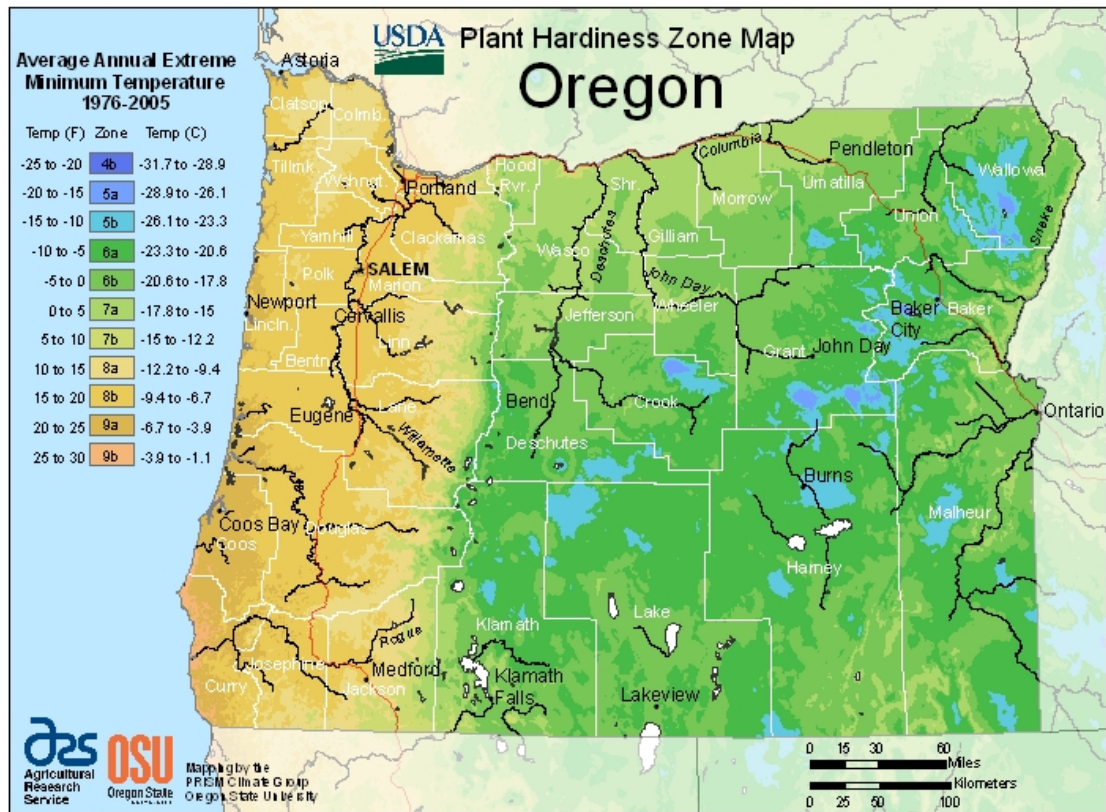


Figure 3: Plant Hardiness Zone (PHZ) Map of Oregon. PHZs are based on the average minimum winter temperature across a 30 year time frame for a region and are used to help growers determine which plants may grow best depending on the zone they inhabit. This risk assessment used PHZs to determine suitable habitat where *Vespa mandarinia* may overwinter. Oregon’s PHZs share some of the same PHZs which are present in *V. mandarinia*’s native ranges. These zones include 6A-9B, which include the majority of Oregon, indicating suitable habitat range overlap for *V. mandarinia* to overwinter in and predate on honeybee populations. (Source: USDA Agricultural Research Service 2020)

‘Greenspace’ habitat suitability

The Pacific Northwest has very dense forest cover. Blackard et al. (2008) estimated that the Pacific Northwest contained the highest densities of forest biomass in the contiguous U.S., with an estimated 9 million ha of forested landcover in Washington, and 13 million

ha of forested landcover for Oregon. Considering that *V. mandarinia* prefers to establish and colonize nests within ‘greenspaces’, the Pacific Northwest serves as a suitable region within the U.S. for it to establish and proliferate. (Figure 4)

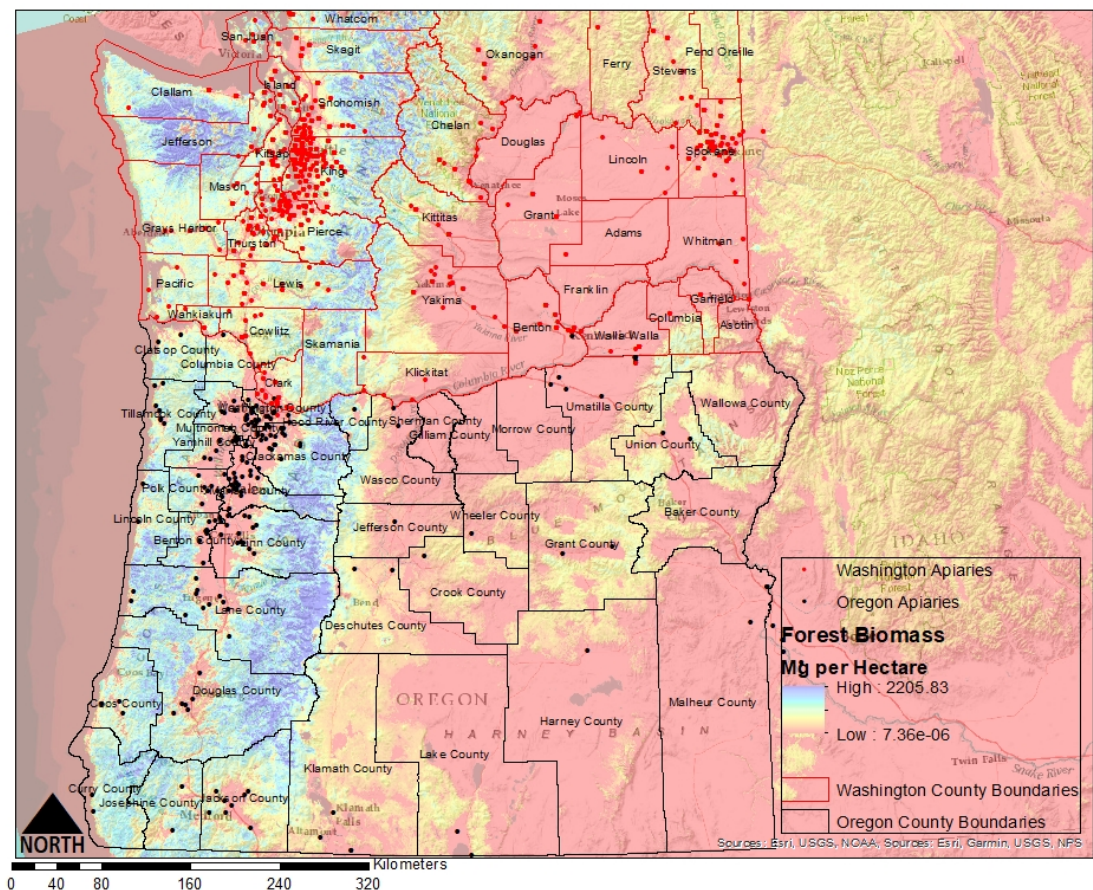


Figure 4: Forest biomass in the Pacific Northwest (Mg/hectare) with apiary distribution in Washington and Oregon. *Vespa mandarinia* prefers to colonize nests in ‘greenspaces’. Considering the density of forest biomass, particularly in the western portions of Washington and Oregon, these regions may serve as suitable habitat for nest establishment. Note the apiary distribution in areas of high forest biomass.

Honey bee colony density and distribution in relation to Plant Hardiness Zones

I obtained data on honey bee colony densities and distribution by county for Washington and Oregon based on registered apiaries and number of individual hives of each apiary. The information was then summed for each county for a total number of individual hives in Washington and Oregon, with percentage for each county relative to the total across both states.

For Washington, the results showed that Grant County, Yakima County, and Skagit County comprised the majority of honey bee colonies and apiaries at 40.2%, 12.9%, and 11.0% respectively, accounting for 64% of the state's apicultural honey bee populations. The remaining 36% of apiary honey bee populations among Washington's counties ranged from 0.01% to 3.5% of the state's total apiary honey bee populations (Figure 5).

Based on this information and the Plant Hardiness Zone Maps of Washington and previously stated habitat suitability for overwintering, the majority of Washington's counties fall within these suitable temperature ranges, with the exception of northern Okanogan, Ferry, Stevens, and Pend Oreille counties (Figure 1). Although the Plant Hardiness Zones are likely an overgeneralization of suitable habitat for *V. mandarinia* it is nonetheless concerning that most of Washington's apicultural industry lies within these zones of potentially suitable habitat (Figure 4).

For Oregon, the results indicated that Malheur County, Linn County, Yamhill County, Clackamas County, and Marion County accounted for 75% of the state's honey bee colonies and apicultural honey bee populations, while the residual 29 counties made up the remaining 25%

(Figure 4). Like Washington, most of Oregon's apicultural industry also falls within areas of potential suitable habitat for *V. mandarinia* (Figure 6).

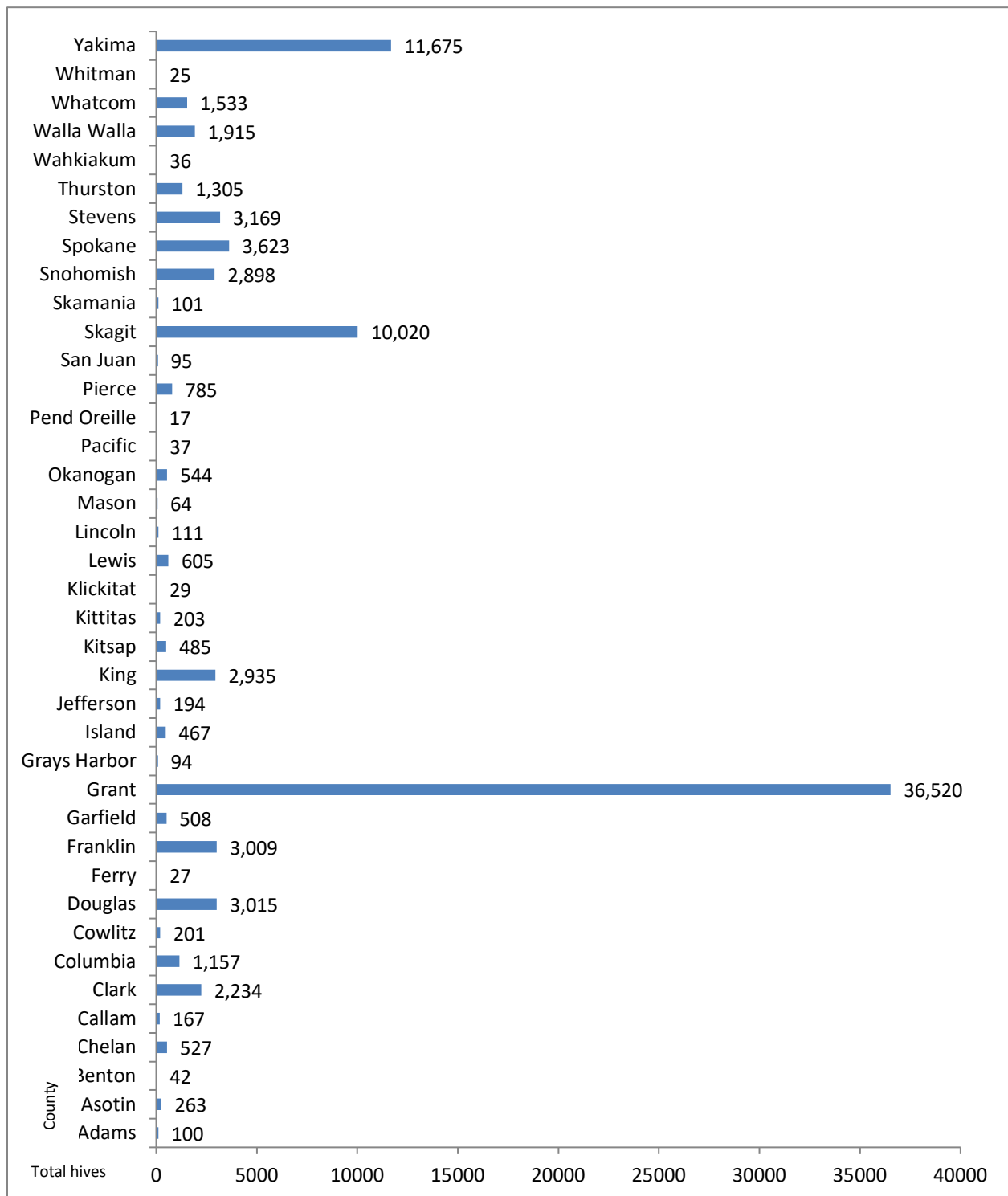


Figure 5: Total honey bee hives by county in Washington State. Note the high proportions of honey bee hives in Grant, Skagit, and Yakima counties relative to the rest of the state. Additionally, these counties also fall within the Plant Hardiness Zones identified to provide suitable habitat where *Vespa mandarinia* may overwinter (FOIA Request from Washington Department of Agriculture).

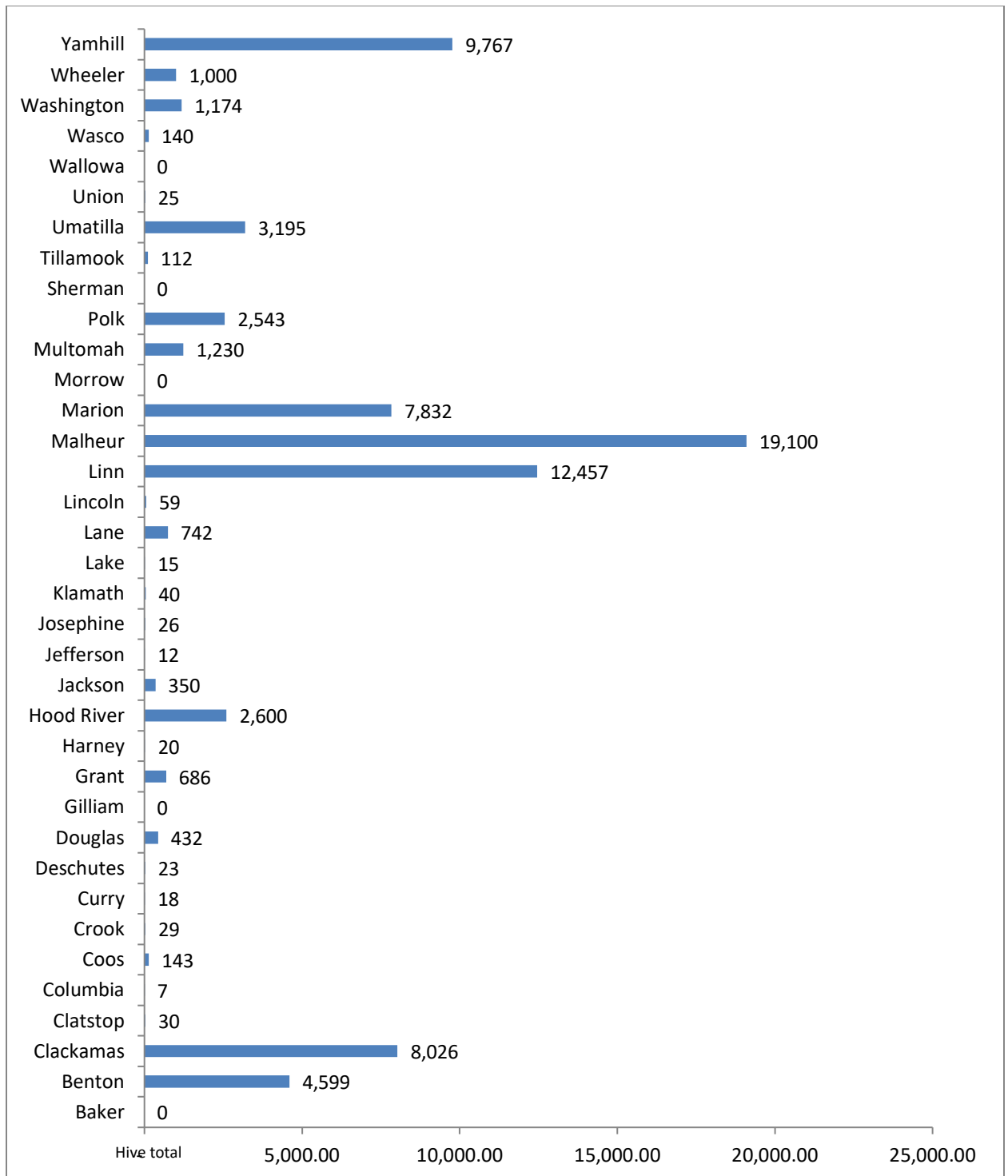


Figure 6: Total honey bee hives by county in Oregon. Note the high proportions of honey bee hives in Malheur, Linn, Clackamas, Marion, and Yamhill counties relative to the rest of the state. Additionally, these counties fall within the Plant Hardiness Zones identified to provide suitable habitat where *Vespa mandarinia* may overwinter (FOIA Request from Oregon Department of Agriculture).

RISK CHARACTERIZATION

To estimate the risk *V. mandarinia* poses to Washington and Oregon, I used a risk rating and scoring system based on an approach used by Schleier et al. (2007) to rank the relative risk of the following categories and criteria: (1) habitat suitability for *V. mandarinia* to overwinter based on plant hardiness zones (ideal PHZ score in Tables 1 & 2), (2) habitat suitability to colonize nests in ‘greenspace’ which was based on dense forest cover in the Pacific Northwest, (3) density of apiaries by county, and (4) the proximity of introduction pathways (major port or freight hubs) that may increase the risk of establishment.

Those counties in Washington and Oregon with high Plant Hardiness Zone designations received a score of ‘3’. Counties with medium to low PHZ designations received a risk rating of ‘2’ or ‘1’, respectively. Similarly, counties with high densities of forest biomass received a risk rating score of ‘3’, and counties with medium to low forest biomass received risk rating scores of ‘2’ and ‘1’. Counties containing high totals of honey bee hives received a risk rating of ‘3’, while those containing low numbers of honey bee hives relative to the rest of the state received risk ratings of ‘2’ and ‘1’. Lastly, the introduction pathway score was based on major port and freight hubs contained in counties of the Pacific Northwest. If a county contained more than one major port or freight hub, that county received a risk rating of ‘3’. If a county contained 1 major port or freight hub, it received a risk rating score of ‘2’. If a county did not contain a major port or freight hub, it received a risk rating of ‘1’.

The scores were then summed across each risk factor for each county for a total possible overall risk score (ORS) of 12. Those counties which received an overall risk score of 1-4

received a ‘low’ risk rating, while counties that received an overall risk score of 5-8 or 9-12 received a risk rating of ‘medium’ or ‘high’, respectively (Tables 1 & 2). These results are also shown visually (Figure 7).

Table 1: Risk rating table for *V. mandarinia* establishment in Washington State. An overall risk rating score (ORS) of 1-4 equals low risk. An ORS of 5-8 equals medium risk, and an ORS of 9-12 equals high risk. Low ORS is highlighted in green, medium in yellow, and high in red.

Washington		Establishment Risk Factor			
County	Ideal PHZ	Apiary density	Dense forest biomass	Proximity to introduction pathway	Overall risk rating
	score	score	score	score	score (ORS)
Adams	2	1	1	2	6
Asotin	2	1	1	2	6
Benton	2	1	1	3	7
Chelan	1	1	3	1	6
Clallam	3	1	3	2	9
Clark	3	2	3	2	10
Columbia	2	2	2	2	8
Cowlitz	3	1	2	3	9
Douglas	2	2	1	1	6
Ferry	1	1	2	1	5
Franklin	2	2	1	3	8
Garfield	2	1	1	1	5
Grant	2	3	1	2	8
Grays Harbor	3	1	3	2	9
Island	3	1	2	1	7
Jefferson	3	1	3	1	8
King	3	2	2	3	10
Kitsap	3	1	2	1	7
Kittias	2	1	2	1	6
Klickitat	2	1	1	1	5
Lewis	3	1	3	1	8

Lincoln	2	1	1	1	5
Mason	3	1	3	1	8
Okanogan	1	1	1	1	4
Pacific	3	1	3	1	8
Pend Oreille1		1	2	1	5
Pierce	3	1	3	3	10
San Juan	3	1	3	1	8
Skagit	2	3	3	2	10
Skamania	2	1	3	1	7
Snohomish	3	2	3	3	11
Spokane	2	2	1	3	8
Stevens	2	2	2	1	7
Thurston	3	2	2	1	8
Wahkiakum	3	1	3	1	8
Walla Walla2		2	1	2	7
Whatcom	2	2	3	2	9
Whitman	2	1	1	1	5
Yakima	2	3	2	1	8

Table 2: Risk rating table for *V. mandarinia* establishment in Oregon. An overall risk rating score (ORS) of 1-4 equals low risk. An ORS of 5-8 equals medium risk, and an ORS of 9-12 equals high risk. Low ORS is highlighted in green, medium in yellow, and high in red.

County	Establishment Risk Factor				Overall risk rating score (ORS)
	Ideal PHZ score	Apiary density score	Dense forest biomass score	Proximity to introduction pathway score	
Baker	1	1	1	2	5
Benton	3	3	2	2	10
Clackamas	3	3	2	1	9
Clatsop	3	1	3	2	9
Columbia	3	1	3	1	8
Coos	3	1	3	2	9
Crook	1	1	1	1	4
Curry	3	1	3	1	8
Deschutes	1	1	1	2	5
Douglas	3	2	3	1	9
Gilliam	2	1	1	1	5
Grant	1	2	1	1	5
Harney	1	1	1	1	4
Hood River	3	2	2	2	9
Jackson	3	1	2	2	8
Jefferson	2	1	1	1	5
Josephine	3	1	3	1	8
Klamath	1	1	2	2	6
Lake	1	1	1	1	4
Lane	3	1	3	2	9
Lincoln	3	1	3	2	9
Linn	3	3	2	2	10
Malheur	1	3	1	1	6
Marrion	3	3	2	2	10
Morrow	2	1	1	1	5
Multnomah	3	2	1	3	9
Polk	3	2	3	2	10
Sherman	2	1	1	1	5
Tillamook	3	1	3	1	8
Umatilla	2	2	1	2	7
Union	2	1	1	2	6
Wallowa	1	1	1	1	4

Wasco	2	1	1	1	5
Washington3		2	1	2	8
Wheeler	2	1	1	1	5
Yamhill	3	3	2	1	9

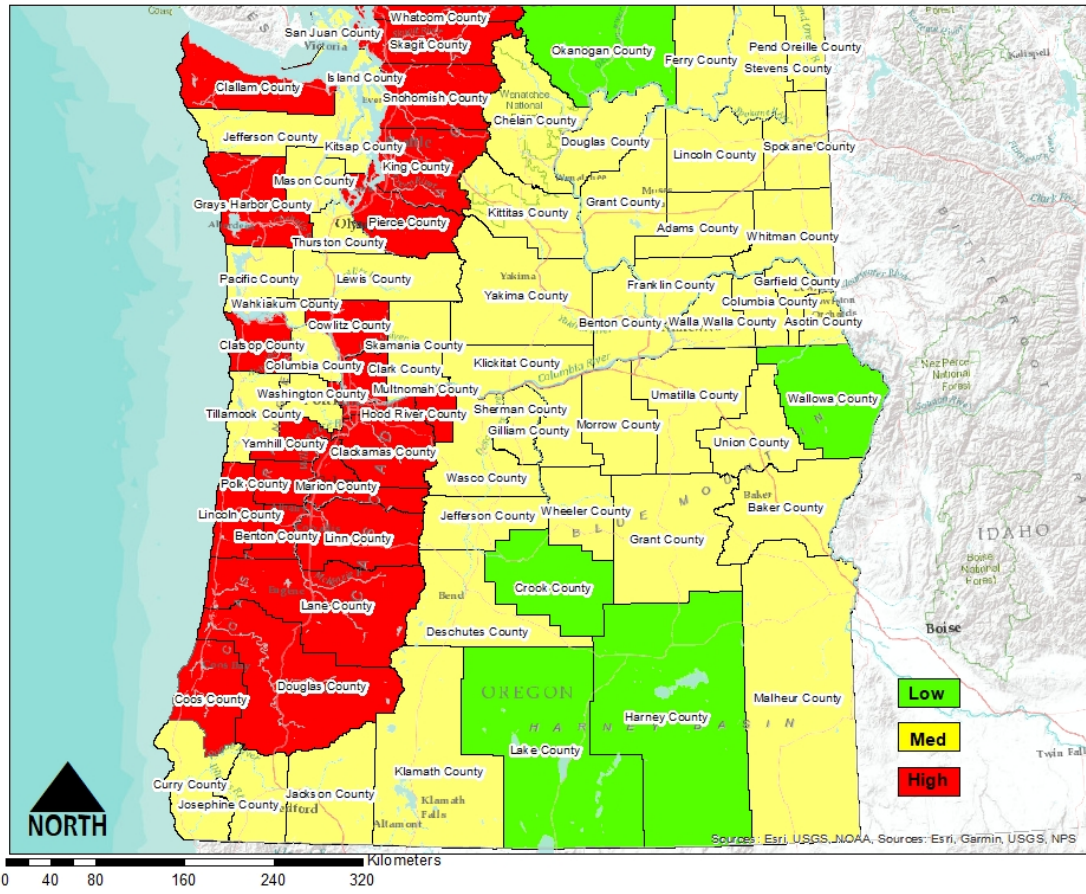


Figure 7: Spatial representation for the overall risk score to each county in the Pacific Northwest for *V. mandarinia* establishment.

The results of the risk characterization were based on the biological requirements of *V. mandarinia* and its known ecological relationships with the environments of the Pacific Northwest. The region provides large swaths of suitable-climate based habitat for queens to overwinter. Similarly, the region is dense in forest biomass, which affords ample greenspace for nest colonization. Furthermore, the majority of honey bee hives and apiaries in Washington and Oregon coincide with these suitable habitats. Lastly, while natural and human-mediated pathways are variable across both states, they must be considered as a possible factor in aiding in the establishment of *V. mandarinia*.

The results of the risk characterization for the establishment of *V. mandarinia* in the Pacific Northwest may come with serious economic consequences for the region, especially for apiculture and crop-pollinated agriculture sectors. Federal and state regulatory agencies, as well as apicultural and agricultural industries should therefore take immediate action to develop plans and methodologies to prevent further naturalization of *V. mandarinia* in Washington and Oregon, with the ultimate goal of complete eradication of the species.

UNCERTAINTY ANALYSIS

My risk assessment had the goal of delineating the biological requirements of *V. mandarinia* and analyzing its known ecological relationships with the environments of the Pacific Northwest to estimate the establishment risk of the hornet on a county by county basis. The results suggest a number of high, medium, and low risk factors that may aid in its establishment in the Pacific Northwest.

However, this risk assessment used a tier-1 approach, which is usually employed when there is a lack of quantitative or spatial data to analyze. Considering that *V. mandarinia* was just recently introduced into the Pacific Northwest, there are few data concerning the species' current distribution within Washington or elsewhere in the Pacific Northwest. Moreover, there is very little published literature on the species, with most of the published research dating back to the 1970s through the 1990s. Furthermore, although there has been somewhat of a recent resurgence in the literature on the species due to the recent introduction of the species into North America, most of this research also relied heavily upon the same aforementioned research that was published decades ago.

With this scarcity of data and lack of knowledge concerning the species' ecological relationships and distribution in the Pacific Northwest, my risk assessment relied on only a few of the biotic and abiotic requirements which may sustain or hamper establishment success of the hornet. For example, the use of Plant Hardiness Zones to delineate habitat suitability for *V. mandarinia* in the Pacific Northwest likely considerably overestimates the areas in which the species could survive its overwintering period and establish new colonies the following year. Accordingly, more detailed research regarding the ecological relationships and life cycle of *V. mandarinia* in the Pacific Northwest needs to be undertaken to form a more complete picture of what can actually be defined as suitable habitat within this region.

Similarly, the honey bee hive distribution and density data was based solely on hives which were managed by registered apiaries and did not take into account hives which may be managed by unregistered beekeepers. In addition, although the risk to apiaries may be easier to estimate, my risk assessment was not able to assess the risk to the pollination services provided

by wild bee populations considering that no data exist on estimates of wild bee populations in the Pacific Northwest.

Additionally, while the use of risk rating systems in qualitative risk assessments aid in producing simple categorizations of risk based on supporting reasoning and documentation (Cox et al. 2005), they are not without limitation. Risk rating systems often lack the confidence to accurately discern between quantitatively small and quantitatively large risks. This can result in errors such as the assignment of higher risk ratings to either a particular, or multiple, risk situations which may in reality actually differ quantitatively by orders of magnitude (Cox et al. 2005).

Furthermore, my risk characterization's reliance on estimating risk on a county by county basis is a rather coarse scale, which likely results in an over or under estimation of the actual risk in a given area. Future assessments should focus on estimating risk in the region at a finer scale.

GOING FORWARD

The establishment of *V. mandarinia* in the Pacific Northwest may pose serious risks to honey bee populations and the economically valuable pollination services they provide. Wild bee populations may be at even more of a risk, considering they would almost certainly not have the same degree or ability to be protected as those colonies managed by apiaries or beekeepers. Federal and state agricultural officials continue to find solitary *V. mandarinia* in northern Washington, and even located the first colonized nest in the region in late October of 2020. Thus, these agencies must remain vigilant and committed to the fight against the establishment of the species.

Higher tiered quantitative risk assessments in conjunction with more rigorous research regarding *V. mandarinia*'s ecological relationships in the Pacific Northwest must continue to go forward and with haste in mind. This is a task which requires the cooperation of industry, federal, state, and local officials, as well as the general public. Moreover, federal and state agricultural officials tasked with managing *V. mandarinia* need to continually develop and modify detection and eradication plans for the pest as new distribution and ecological relationship data become readily available to prevent the species from becoming an established pest in the Pacific Northwest.

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