



Universitat
de les Illes Balears

DOCTORAL THESIS
2024

**Theoretical and data-driven models in
Ecology**

Àlex Giménez Romero



Universitat
de les Illes Balears

DOCTORAL THESIS 2024

Doctoral programme in Physics

Theoretical and data-driven models in Ecology

Àlex Giménez Romero

Thesis Supervisor: Manuel A. Matías
Thesis Tutor: Cristóbal López Sánchez

Doctor by the Universitat de les Illes Balears

Supervisors:
Manuel Matías

Àlex Giménez Romero.
Theoretical and data-driven models in Ecology. ©
Palma de Mallorca, July 2024

A en Manuel Miranda
pel seu suport i ajuda
durant tots aquests anys.
Sempre estaràs amb mi.
i recordare sempre
el que em vas ensenyar.

Dr Manuel A. Matías of the Consejo Superior de Investigaciones Científicas (CSIC)

I DECLARE:

That the thesis title *Theoretical and data-driven models in Ecology*, presented by Àlex Giménez Romero to obtain a doctoral degree, has been completed under my supervision and meets the requirements to opt for an International Doctorate.

For all intents and purposes, I hereby sign this document.

Signature

Dr. Manuel A. Matías
Thesis Supervisor

Palma de Mallorca, July 2024

Acknowledgements

Acknowledgements go here.

Resum

El resum va aquí.

Resumen

El resumen va aquí.

Abstract

Abstract goes here.

Contents

I

Introduction

| | | |
|----------|---|----------|
| 1 | The global biodiversity crisis | 0 |
| 1.1 | Introduction | 0 |
| 1.2 | The Mass Mortality Event of <i>Pinna nobilis</i> | 0 |
| 1.3 | <i>Xylella fastidiosa</i> : an emerging global threat | 0 |
| 1.4 | The global decline of seagrasses: the case of <i>Posidonia oceanica</i> | 0 |
| 1.5 | Coral reefs: a global crisis | 0 |

| | | |
|----------|--------------------------|----------|
| 2 | Models in Ecology | 1 |
|----------|--------------------------|----------|

| | | |
|-------|-----------------------------|---|
| 2.1 | Introduction | 1 |
| 2.2 | Why do we need models? | 1 |
| 2.3 | Theoretical modelling | 1 |
| 2.3.1 | Dynamical systems | 1 |
| 2.3.2 | Compartmental models | 1 |
| 2.3.3 | Individual-based models | 1 |
| 2.4 | Data-driven modelling | 1 |
| 2.4.1 | Species Distribution Models | 1 |
| 2.4.2 | Artificial Intelligence | 1 |

| | | |
|----------|---|----------|
| 3 | Main original contributions of this thesis | 3 |
|----------|---|----------|

II

Modelling parasite-produced marine diseases

| | | |
|----------|--|----------|
| 4 | Modelling parasite-produced marine diseases: The case of the mass mortality event of <i>Pinna nobilis</i> | 7 |
| 5 | Spatial effects in parasite-induced marine diseases of immobile hosts | 9 |

III**Realistic models for vector-borne plant diseases**

- 6 Vector-borne diseases with non-stationary vector populations: the case of growing and decaying populations 13
- 7 A compartmental model for *Xylella fastidiosa* diseases with explicit vector seasonal dynamics 15
- 8 Degree-day-based model to predict egg hatching of *Philaenus spumarius* (Hemiptera: Aphrophoridae), the main vector of *Xylella fastidiosa* in Europe 17

IV**Modelling the risk of vector-borne plant diseases**

- 9 Global predictions for the risk of establishment of Pierce's disease of grapevines 21
- 10 Global warming significantly increases the risk of Pierce's disease epidemics in European vineyards 23
- 11 High-resolution climate data reveals increased risk of Pierce's Disease for grapevines worldwide 25

V**Data-driven methods for global ecological problems**

- 12 A comprehensive dataset on global coral reefs size and geometry 29
- 13 Universal spatial properties of coral reefs 31
- 14 Mapping the distribution of seagrass meadows from space with deep convolutional neural networks 33

List of publications

1. Susana Flecha et al. "pH trends and seasonal cycle in the coastal Balearic Sea reconstructed through machine learning". In: *Scientific Reports* 12.1 (July 2022), page 12956. ISSN: 2045-2322. DOI: [10.1038/s41598-022-17253-5](https://doi.org/10.1038/s41598-022-17253-5). URL: <https://doi.org/10.1038/s41598-022-17253-5>
2. Àlex Giménez-Romero et al. "Spatial effects in parasite-induced marine diseases of immobile hosts". In: *Royal Society Open Science* 9.8 (2022), page 212023. DOI: [10.1098/rsos.212023](https://doi.org/10.1098/rsos.212023). eprint: <https://royalsocietypublishing.org/doi/pdf/10.1098/rsos.212023>. URL: <https://royalsocietypublishing.org/doi/abs/10.1098/rsos.212023>
3. Àlex Giménez-Romero, Rosa Flaquer-Galmés, and Manuel A. Matías. "Vector-borne diseases with nonstationary vector populations: The case of growing and decaying populations". In: *Phys. Rev. E* 106 (5 Nov. 2022), page 054402. DOI: [10.1103/PhysRevE.106.054402](https://doi.org/10.1103/PhysRevE.106.054402). URL: <https://link.aps.org/doi/10.1103/PhysRevE.106.054402>
4. Alex Giménez-Romero et al. "Global predictions for the risk of establishment of Pierce's disease of grapevines". In: *Communications Biology* 5.1 (Dec. 2022), page 1389. ISSN: 2399-3642. DOI: [10.1038/s42003-022-04358-w](https://doi.org/10.1038/s42003-022-04358-w). URL: <https://doi.org/10.1038/s42003-022-04358-w>
5. Àlex Giménez-Romero, Eduardo Moralejo, and Manuel A. Matías. "A Compartmental Model for *Xylella fastidiosa* Diseases with Explicit Vector Seasonal Dynamics". In: *Phytopathology®* 113.9 (2023). PMID: 36774557, pages 1686–1696. DOI: [10.1094/PHYTO-11-22-0428-V](https://doi.org/10.1094/PHYTO-11-22-0428-V). eprint: <https://doi.org/10.1094/PHYTO-11-22-0428-V>. URL: <https://doi.org/10.1094/PHYTO-11-22-0428-V>
6. Clara Lago et al. "Degree-day-based model to predict egg hatching of *Philaenus spumarius* (Hemiptera: Aphrophoridae), the main vector of *Xylella fastidiosa* in Europe". In: *Environmental Entomology* 52.3 (Apr. 2023), pages 350–359. ISSN: 0046-225X. DOI: [10.1093/ee/nvad013](https://doi.org/10.1093/ee/nvad013). eprint: <https://academic.oup.com/ee/article-pdf/52/3/350/50615564/nvad013.pdf>. URL: <https://doi.org/10.1093/ee/nvad013>

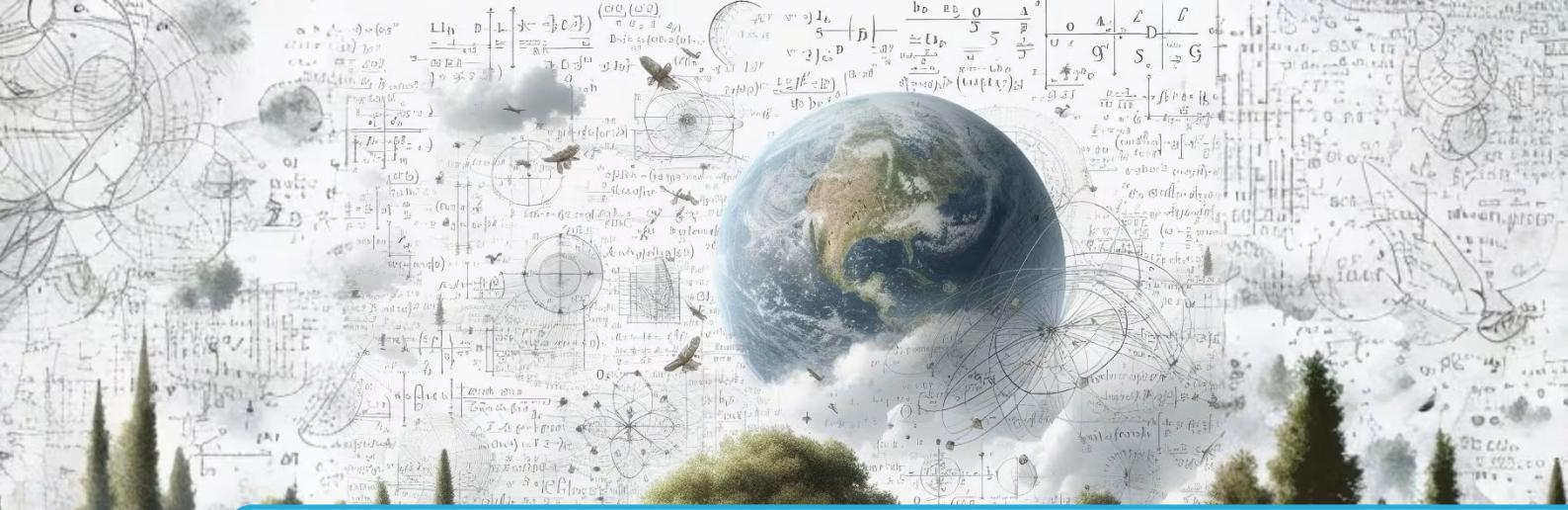
Introduction

| | | |
|----------|---|----------|
| 1 | The global biodiversity crisis | 0 |
| 1.1 | Introduction | 0 |
| 1.2 | The Mass Mortality Event of <i>Pinna nobilis</i> | 0 |
| 1.3 | <i>Xylella fastidiosa</i> : an emerging global threat | 0 |
| 1.4 | The global decline of seagrasses: the case of <i>Posidonia oceanica</i> 0 | 0 |
| 1.5 | Coral reefs: a global crisis | 0 |
| 2 | Models in Ecology | 1 |
| 2.1 | Introduction | 1 |
| 2.2 | Why do we need models? | 1 |
| 2.3 | Theoretical modelling | 1 |
| 2.4 | Data-driven modelling | 1 |
| 3 | Main original contributions of this thesis | 3 |

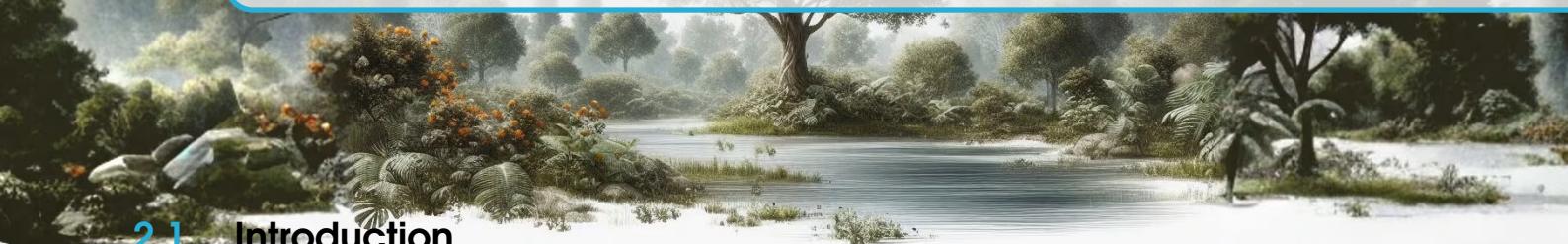


1. The global biodiversity crisis

- 1.1 Introduction
- 1.2 The Mass Mortality Event of *Pinna nobilis*
- 1.3 *Xylella fastidiosa*: an emerging global threat
- 1.4 The global decline of seagrasses: the case of *Posidonia oceanica*
- 1.5 Coral reefs: a global crisis



2. Models in Ecology



2.1 Introduction

2.2 Why do we need models?

2.3 Theoretical modelling

2.3.1 Dynamical systems

2.3.2 Compartmental models

2.3.3 Individual-based models

2.4 Data-driven modelling

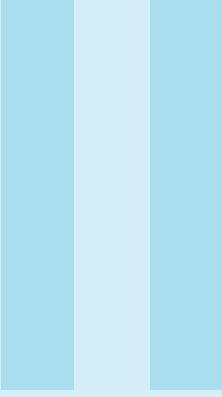
2.4.1 Species Distribution Models

2.4.2 Artificial Intelligence



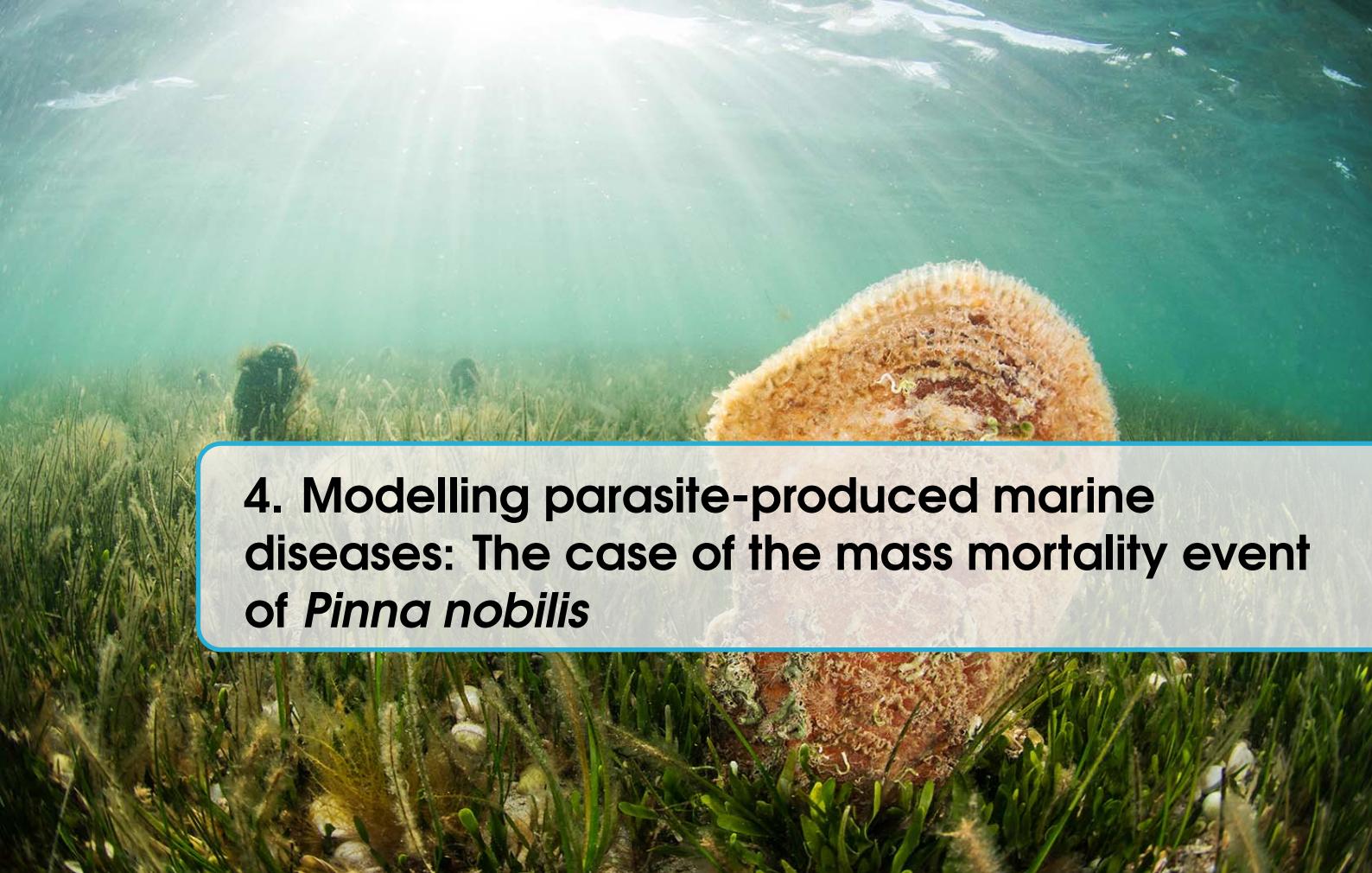
3. Main original contributions of this thesis





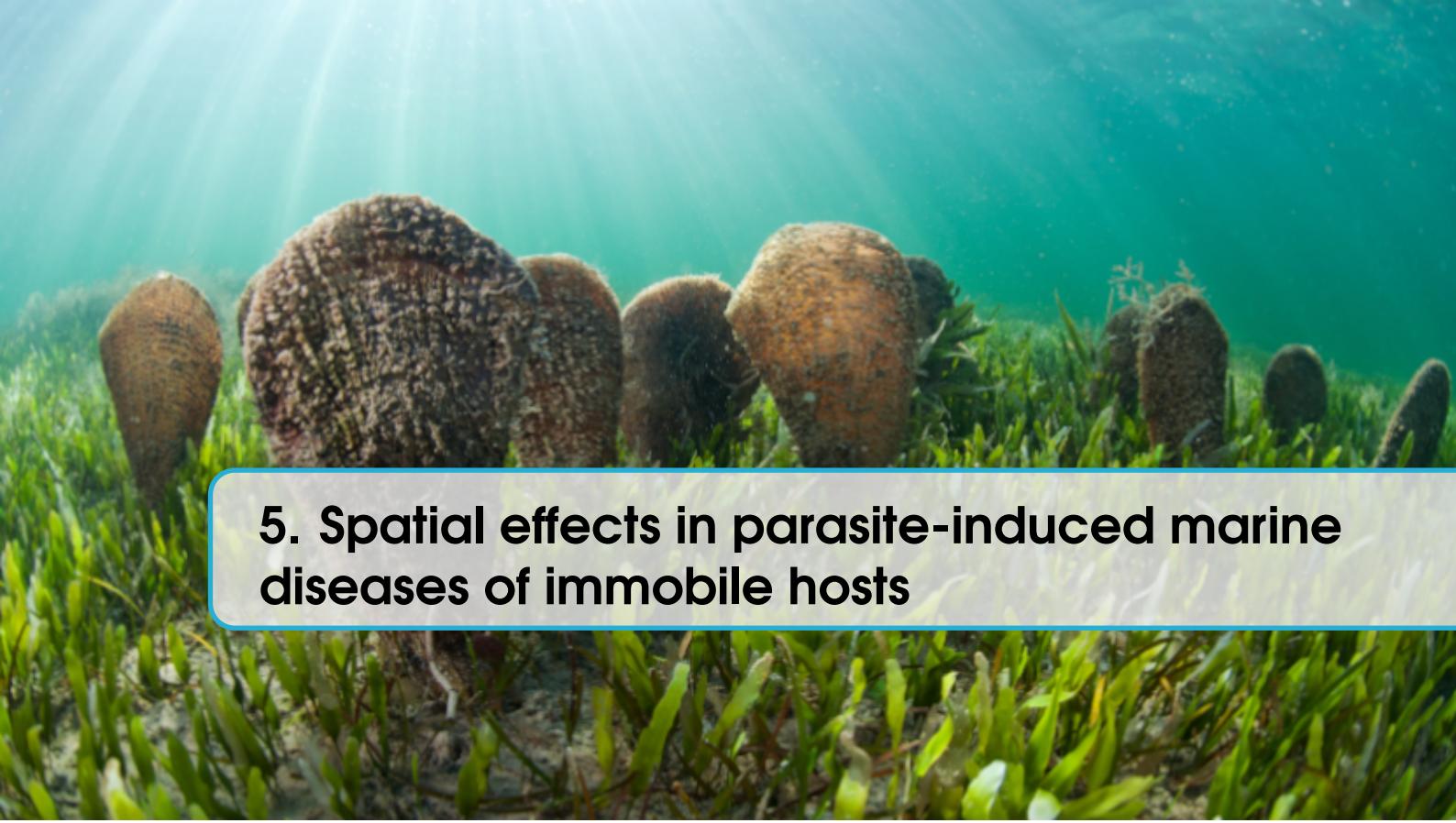
Modelling parasite-produced marine diseases

- | | | |
|---|--|---|
| 4 | Modelling parasite-produced marine diseases: The case of the mass mortality event of <i>Pinna nobilis</i> | 7 |
| 5 | Spatial effects in parasite-induced marine diseases of immobile hosts | 9 |

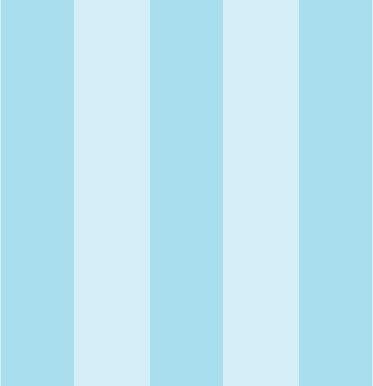


A photograph of an underwater environment. In the foreground, a large, spiny sea urchin rests on a bed of green seagrass. Sunlight filters down from the surface in bright rays, illuminating the clear blue water and the sandy ocean floor.

4. Modelling parasite-produced marine diseases: The case of the mass mortality event of *Pinna nobilis*

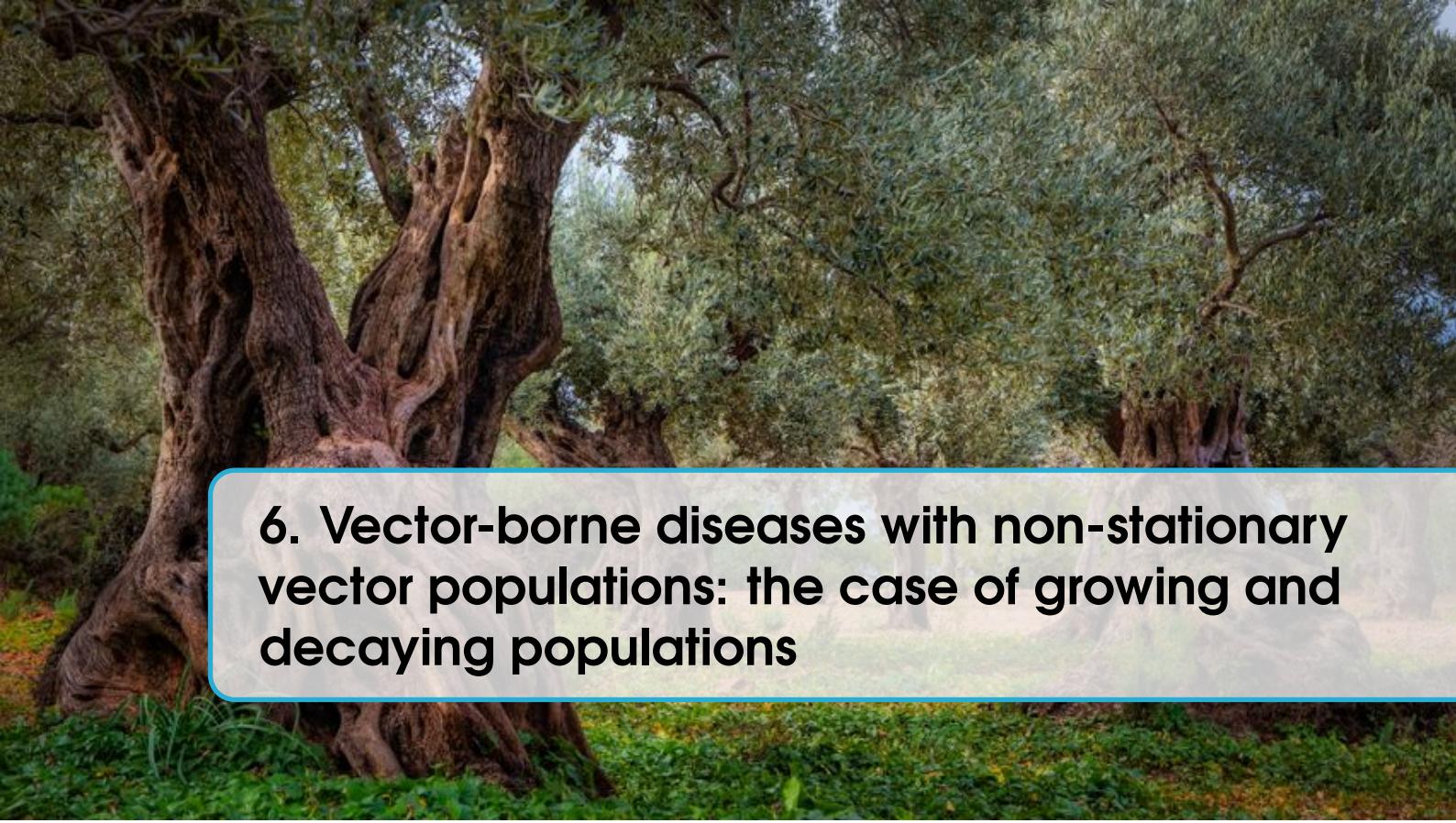
A photograph of an underwater environment. In the foreground, several large, brown, textured objects, possibly sea urchins or coral, are nestled among dense green seagrass. Sunlight filters down from the surface in bright rays, creating a clear blue-green background.

5. Spatial effects in parasite-induced marine diseases of immobile hosts

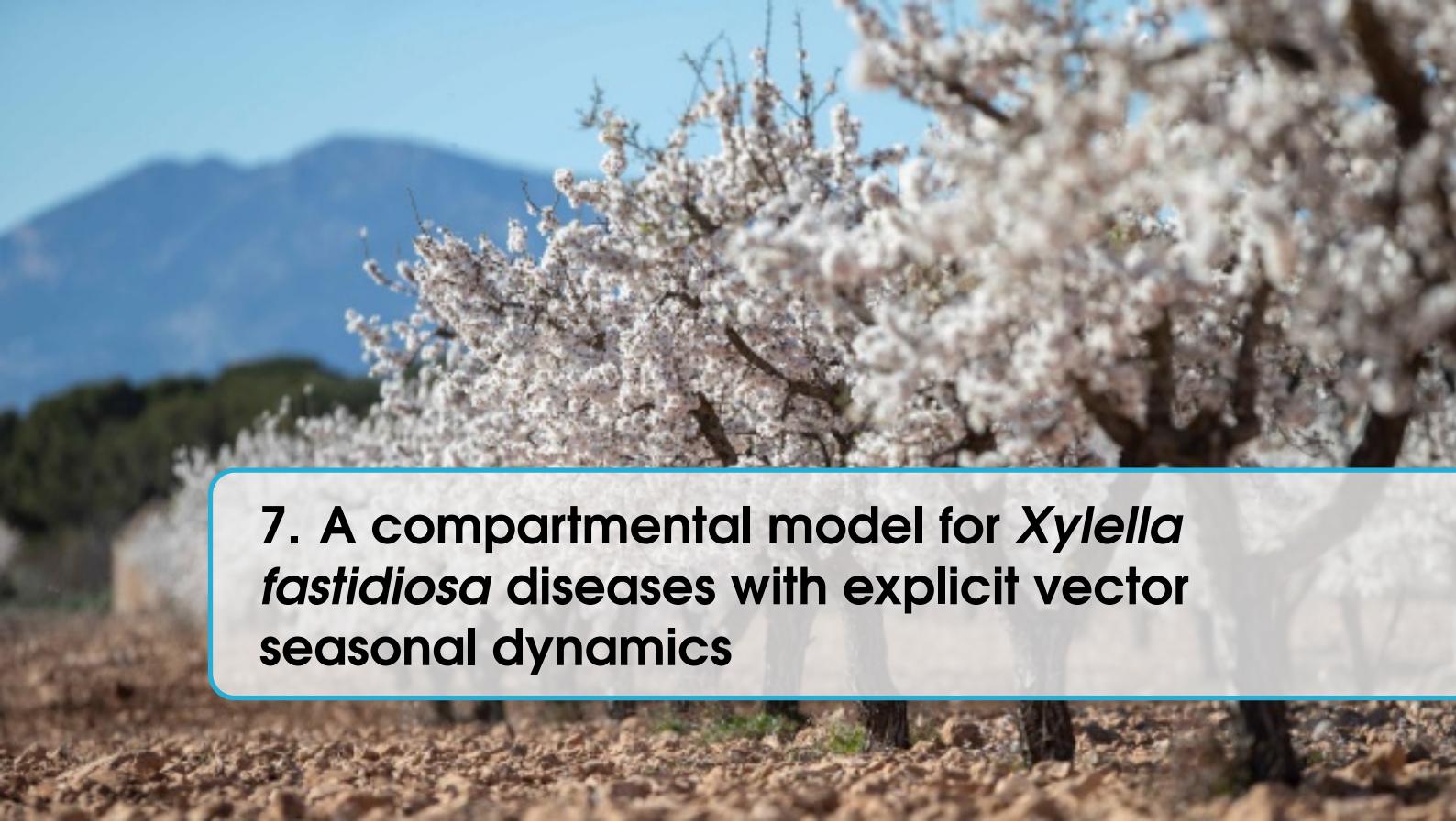


Realistic models for vector-borne plant diseases

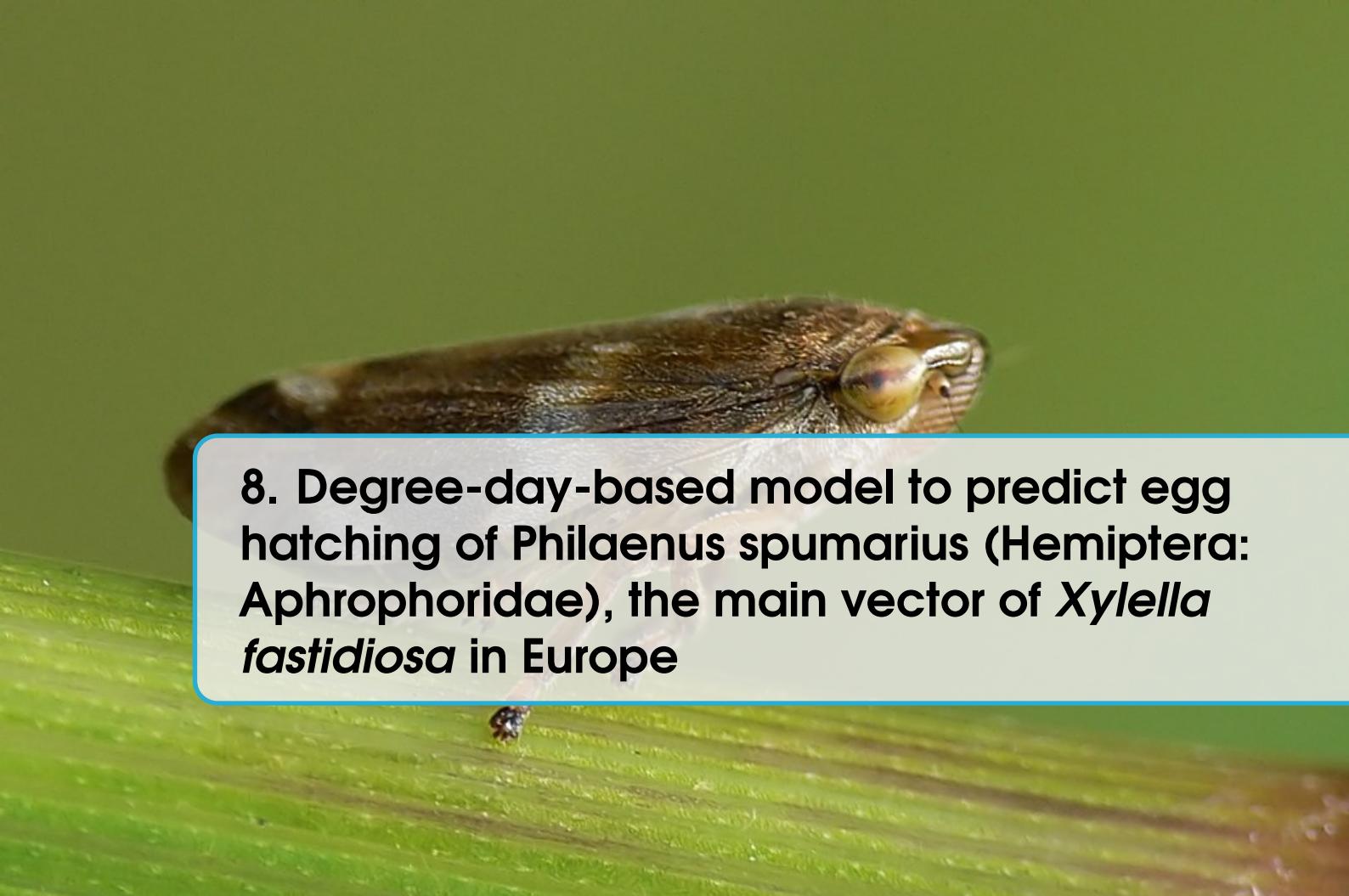
- 6 Vector-borne diseases with non-stationary vector populations: the case of growing and decaying populations 13
- 7 A compartmental model for *Xylella fastidiosa* diseases with explicit vector seasonal dynamics . 15
- 8 Degree-day-based model to predict egg hatching of *Philaenus spumarius* (Hemiptera: Aphrophoridae), the main vector of *Xylella fastidiosa* in Europe 17



6. Vector-borne diseases with non-stationary vector populations: the case of growing and decaying populations



7. A compartmental model for *Xylella fastidiosa* diseases with explicit vector seasonal dynamics

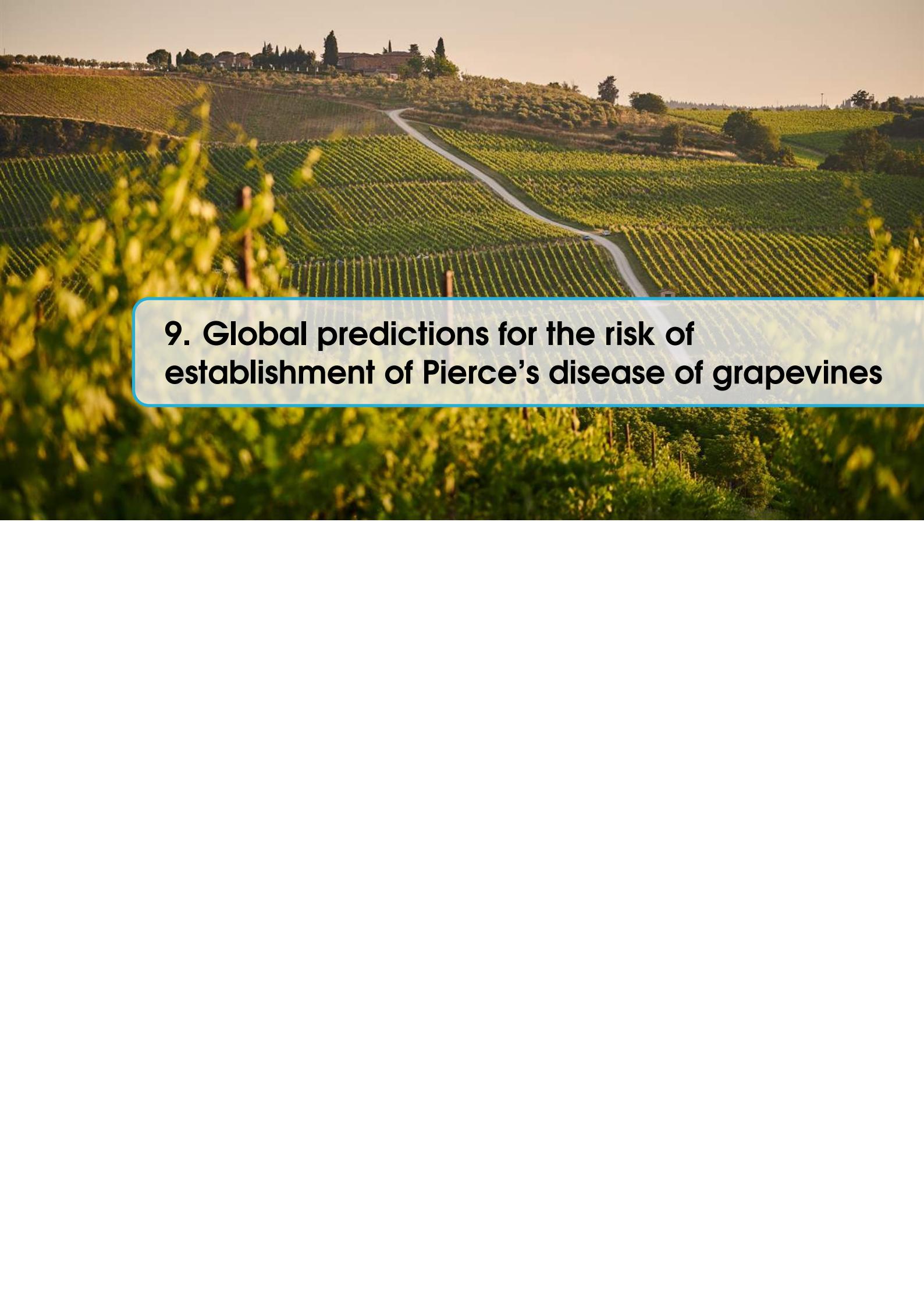


8. Degree-day-based model to predict egg hatching of *Philaenus spumarius* (Hemiptera: Aphrophoridae), the main vector of *Xylella fastidiosa* in Europe



Modelling the risk of vector-borne plant diseases

- 9 Global predictions for the risk of establishment of Pierce's disease of grapevines 21**
- 10 Global warming significantly increases the risk of Pierce's disease epidemics in European vineyards 23**
- 11 High-resolution climate data reveals increased risk of Pierce's Disease for grapevines worldwide .. 25**

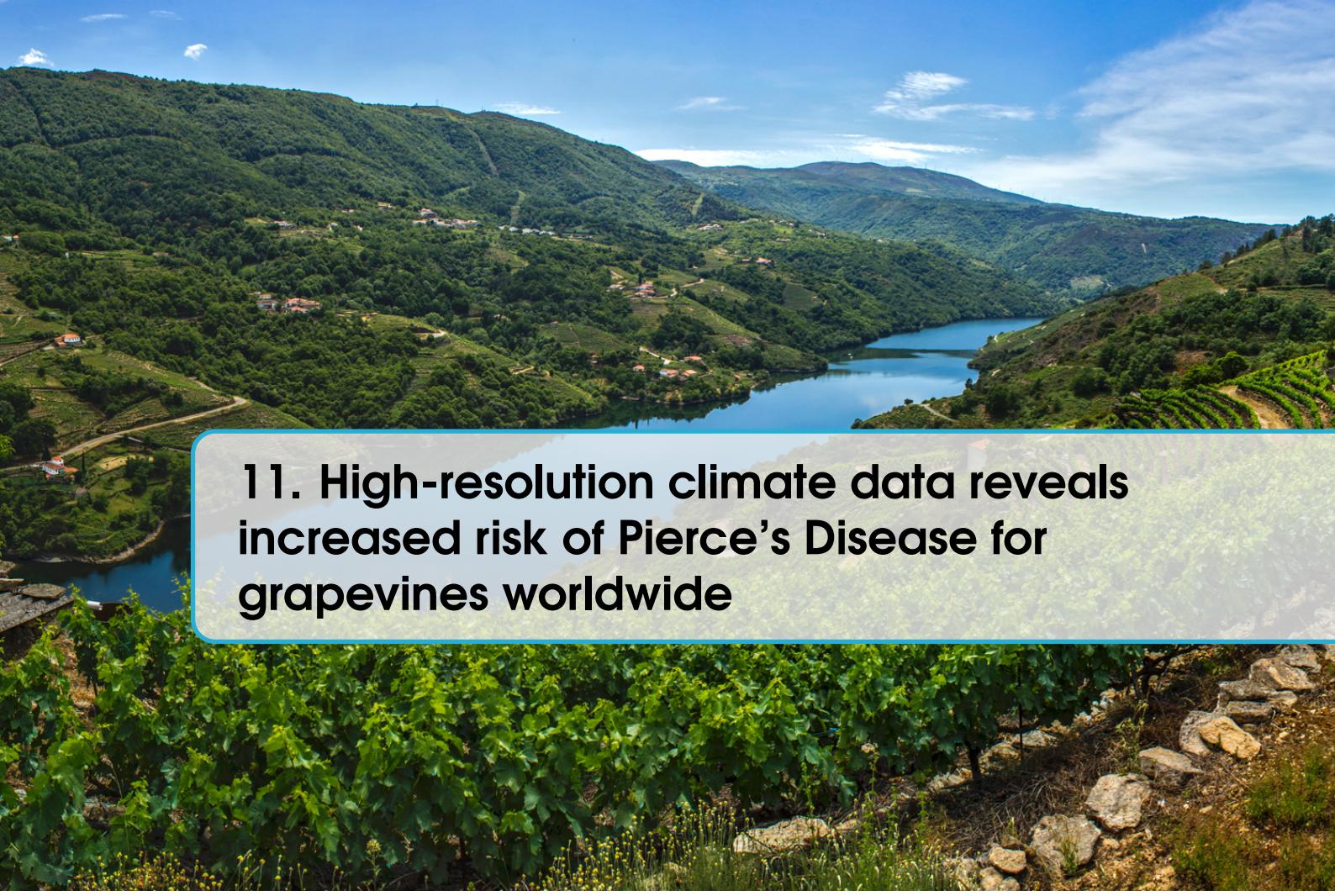


A wide-angle photograph of a vineyard landscape. The foreground is filled with the green, leafy tops of grapevines, their rows forming a grid pattern across the hillside. In the middle ground, a winding road cuts through the vines, leading towards a cluster of buildings and trees on a hilltop in the distance. The sky is a clear, pale yellow, suggesting either sunrise or sunset.

9. Global predictions for the risk of establishment of Pierce's disease of grapevines



10. Global warming significantly increases the risk of Pierce's disease epidemics in European vineyards



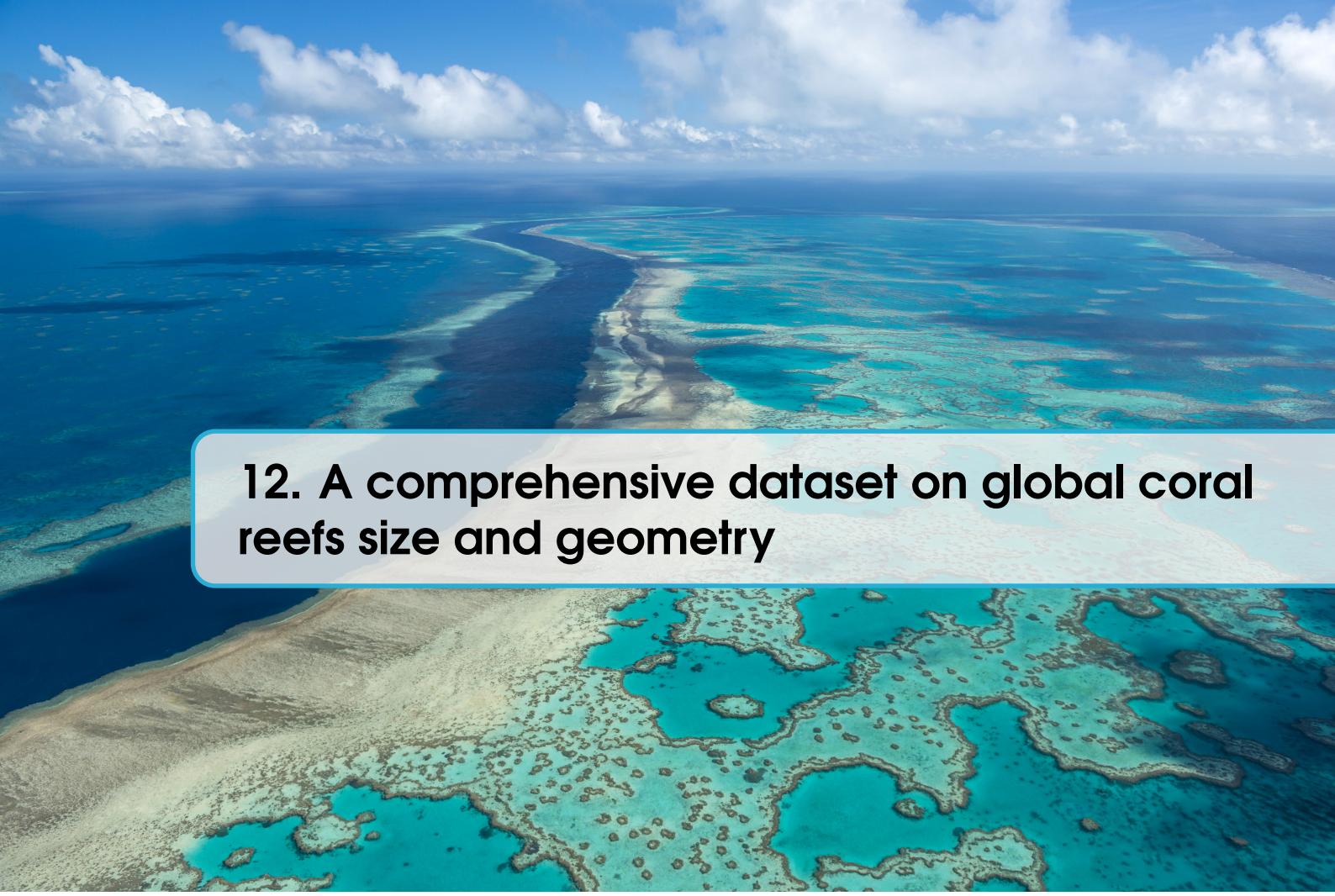
11. High-resolution climate data reveals increased risk of Pierce's Disease for grapevines worldwide



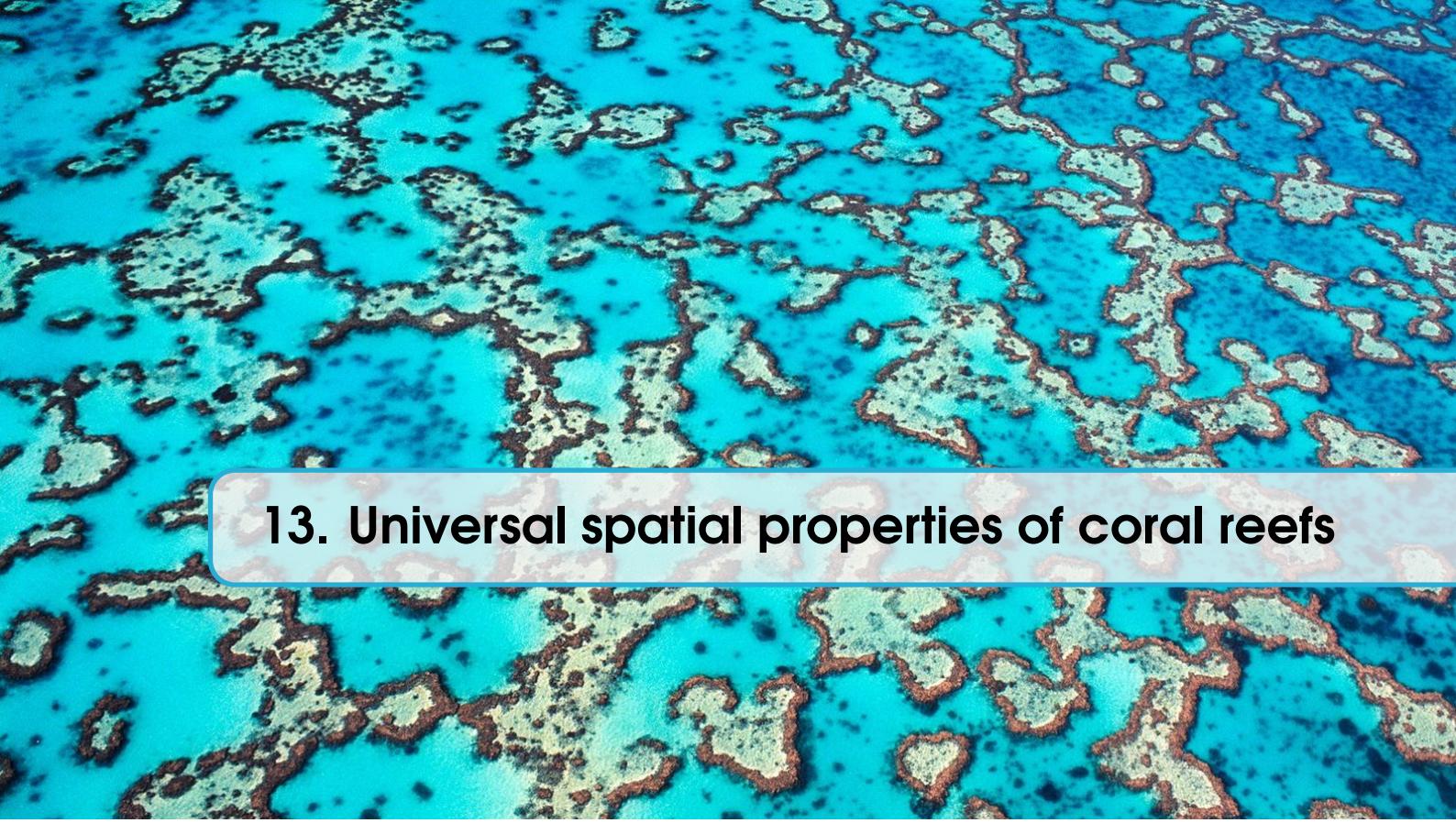


Data-driven methods for global ecological problems

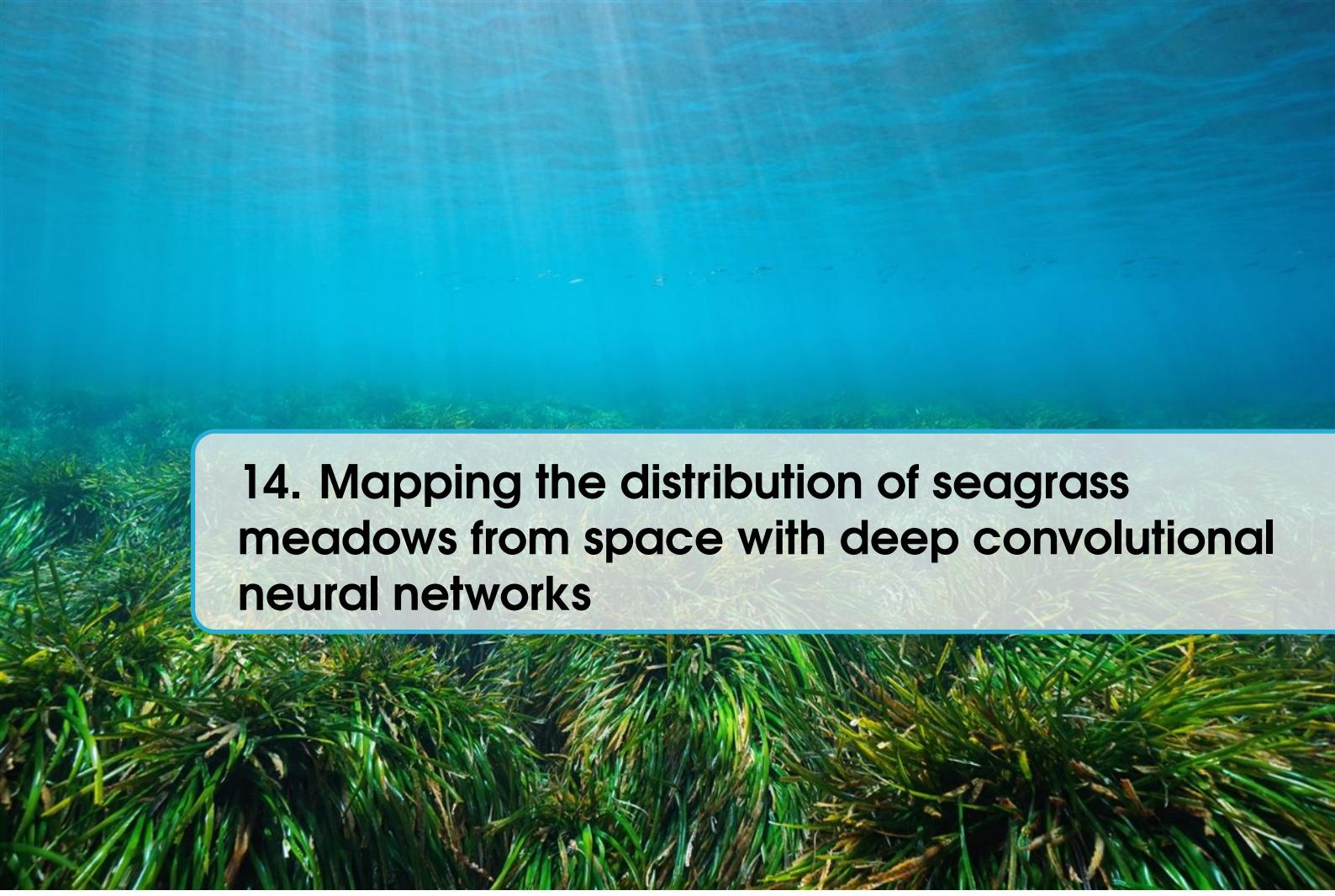
- | | | |
|----|---|----|
| 12 | A comprehensive dataset on global coral reefs size and geometry | 29 |
| 13 | Universal spatial properties of coral reefs | 31 |
| 14 | Mapping the distribution of seagrass meadows from space with deep convolutional neural networks | 33 |



12. A comprehensive dataset on global coral reefs size and geometry



13. Universal spatial properties of coral reefs

A photograph of a seagrass meadow underwater. The dense, green, blade-like leaves of the seagrass grow in patches across the sandy ocean floor. The water is clear, allowing light to penetrate and illuminate the plants. In the background, the sandy bottom and some distant marine life are visible.

14. Mapping the distribution of seagrass meadows from space with deep convolutional neural networks

Bibliography

Bibliography

- [1] Susana Flecha et al. “pH trends and seasonal cycle in the coastal Balearic Sea reconstructed through machine learning”. In: *Scientific Reports* 12.1 (July 2022), page 12956. ISSN: 2045-2322. DOI: [10.1038/s41598-022-17253-5](https://doi.org/10.1038/s41598-022-17253-5). URL: <https://doi.org/10.1038/s41598-022-17253-5> (cited on page 15).
- [2] Alex Giménez-Romero et al. “Global predictions for the risk of establishment of Pierce’s disease of grapevines”. In: *Communications Biology* 5.1 (Dec. 2022), page 1389. ISSN: 2399-3642. DOI: [10.1038/s42003-022-04358-w](https://doi.org/10.1038/s42003-022-04358-w). URL: <https://doi.org/10.1038/s42003-022-04358-w> (cited on page 15).
- [3] Àlex Giménez-Romero, Rosa Flaquer-Galmés, and Manuel A. Matías. “Vector-borne diseases with nonstationary vector populations: The case of growing and decaying populations”. In: *Phys. Rev. E* 106 (5 Nov. 2022), page 054402. DOI: [10.1103/PhysRevE.106.054402](https://doi.org/10.1103/PhysRevE.106.054402). URL: <https://link.aps.org/doi/10.1103/PhysRevE.106.054402> (cited on page 15).
- [4] Àlex Giménez-Romero, Eduardo Moralejo, and Manuel A. Matías. “A Compartmental Model for Xylella fastidiosa Diseases with Explicit Vector Seasonal Dynamics”. In: *Phytopathology®* 113.9 (2023). PMID: 36774557, pages 1686–1696. DOI: [10.1094/PHYTO-11-22-0428-V](https://doi.org/10.1094/PHYTO-11-22-0428-V). eprint: <https://doi.org/10.1094/PHYTO-11-22-0428-V>. URL: <https://doi.org/10.1094/PHYTO-11-22-0428-V> (cited on page 15).
- [5] Àlex Giménez-Romero et al. “Spatial effects in parasite-induced marine diseases of immobile hosts”. In: *Royal Society Open Science* 9.8 (2022), page 212023. DOI: [10.1098/rsos.212023](https://doi.org/10.1098/rsos.212023). eprint: <https://royalsocietypublishing.org/doi/pdf/10.1098/rsos.212023>. URL: <https://royalsocietypublishing.org/doi/abs/10.1098/rsos.212023> (cited on page 15).
- [6] Clara Lago et al. “Degree-day-based model to predict egg hatching of *Philaenus spumarius* (Hemiptera: Aphrophoridae), the main vector of *Xylella fastidiosa* in Europe”. In: *Environmental Entomology* 52.3 (Apr. 2023), pages 350–359. ISSN: 0046-225X. DOI: [10.1093/ee/nvad013](https://doi.org/10.1093/ee/nvad013). eprint: <https://academic.oup.com/ee/article-pdf/52/3/350/50615564/nvad013.pdf>. URL: <https://doi.org/10.1093/ee/nvad013> (cited on page 15).

