Environment Protection and Biodiversity Conservation Act 1999
Annual Compliance Report

EPBC Approval: 2011/5815

Project: Yandicoogina Junction South West and Oxbow Iron Ore Project, WA

Report period: 1 January – 31 December 2020

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1 Description of activities

EPBC approval number:	2011/5815
Project name:	Yandicoogina Junction South West and Oxbow Iron Ore Project, WA
Approval holder:	Hamersley Iron Pty Ltd
Approval holder's Australian Business Number:	49 004 558 276
Approved action:	To develop new mine pits and supporting infrastructure, at Yandicoogina, central Pilbara region of WA, as described in the referral received by the department on 20 January 2011.
Location of the project:	Central Pilbara region of WA
Reporting period:	1 January 2020 to 31 December 2020
Report preparation date:	30 April 2021
Implementation phase(s) during reporting period:	Operational

2 Audit table

Details of compliance with each condition under EPBC approval 2011/5815 are presented in Table 1.

Table 1: EPBC Approval Conditions Compliance Table: EPBC 2011/5815 – Yandicoogina Junction South West and Oxbow Iron Ore Project, WA

Condition Number	Condition	Compliance status	Evidence/Comments
1	To protect habitat for the **Northern Quoll** and **Pilbara Olive Python** **disturbance** of vegetation must: a) not exceed a total of 2,200 hectares and must only occur within the **development footprint**; and b) not exceed 40 hectares within the floodplain and riparian vegetation zone associated with **Marillana Creek** located within the **development footprint**.	Compliant	Aerial photography was collected during the reporting period to reconcile ground disturbance and the prescribed clearing limits were not exceeded. Disturbance is controlled through a RTIO permitting process and mapped using GIS through on ground and / or aerial surveying.
2	The person taking the action must establish and maintain an **EPBC Act listed threatened species** Register on a publicly available website. The Register must record any sightings of **EPBC Act listed threatened species**, alive or dead, in the **project area** no less than every three months during **construction**, and no less than every 12 months during **operation**. The web address of the register must be provided to the **department** within 30 days of establishment.	Compliant	The Threatened Species register, Yandi_EPBC_National Matters of Environmental Significance Register (our ref: RTIO-HSE-0163656) was established in 2013 and is publicly available at: https://www.riotinto.com/-/media/Content/Documents/Operations/Pilbara/RT-Pilbara-Threatened-species-register.pdf?rev=d0456da8eae148b8b7ac622a36aae3fb The register is updated no less than every 12 months (annually) as the project was in Operations phase for 2020.

Condition Number	Condition	Compliance status	Evidence/Comments
3	The person taking the action must develop a staff environmental induction to be undertaken by all staff, including contractors, prior to the **commencement** of their duties and annually thereafter. The induction material must include, but not necessarily be limited to: a) clear colour images and simple descriptions of the ecology and diagnostic features of **EPBC Act listed threatened species** and their habitat; b) protocols for reporting sightings, including vehicle strike (including GPS coordinates), of **EPBC Act listed threatened species** within seven days to the officer in charge of implementing the **EPBC Act listed threatened species** Register described in condition 2; c) reference to the penalties imposed for causing intentional harm to **EPBC Act listed threatened species**; and d) legal and on site environmental responsibilities.	Compliant	All new staff and contractors commencing work at Yandicoogina Operations are required to complete the Yandicoogina Essentials Induction prior to starting work at the site (our ref: RTIO-HR-0056810). The induction includes a section on the EPBC Approval, the associated EPBC threatened species, reporting protocols, legal penalties and responsibilities. An online EPBC mandatory qualification (Environmental Protection Induction) is also a requirement for Yandi personnel, this is accessed via the Rio Tinto online training system "Scodle". Refresher training for the induction is required annually. Training records are maintained by Learning and Development. Visitors to site are required to complete the Visitors Induction which also includes information on EPBC Act listed threatened species known to exist within the operational area.
4	The person taking the action must display the information required in condition 3) a) on signs or posters around staff amenities, construction camps and material/equipment depots, and on laminated cards for all staff vehicles. The signs, posters and laminated cards must also state that the **Pilbara Olive Python** is slow moving and highly susceptible to road strike.	Compliant	Signage is on display widely across site including camp and administration offices, and laminated cards with this information are maintained in all Yandicoogina RTIO site vehicles. Yandicoogina MS1038 EPBC Act vehicle information card (our ref: RTIO-HSE-0163384). Yandicoogina MS1038 EPBC Act poster (our ref: RTIO-HSE-0163382).
5	In the event one or more **Northern Quoll** and/or **Pilbara Olive Python** individuals are detected within the **development footprint**, the person taking the action must limit vehicle speeds outside the **active pit areas**, excluding automated haulage machines, to 40 km per hour on all roads within the **development footprint** between dusk and dawn until no **Northern Quolls** and/or **Pilbara Olive Python** individuals are sighted for a continuous period of four weeks.	Not applicable	No Northern Quolls or Pilbara Olive Pythons were detected in the development footprint during the reporting period. Personnel have access to the Yandicoogina EPBC species reporting procedure on the Health, Safety, Environment and Quality intranet (our ref: RTIO-HSE-0169976).

Condition Number	Condition	Compliance status	Evidence/Comments
6	The person taking the action must ensure that all vehicles, machinery, and equipment remain within the **development footprint**, and must prevent off road driving, unless in case of an emergency.	Compliant	All vehicles, machinery, and equipment remained in the development footprint. Compliance is ensured through designated light vehicle and heavy vehicle access and haul roads. Personnel are not permitted to drive outside of the designated road system. This requirement is included in the Yandicoogina Site Essentials induction which all personnel are required to complete prior to commencing work on site. No emergency situations required vehicle access outside of the development footprint during the reporting period.
7	The person taking the action must ensure that all vehicles, machinery and equipment are prevented from accessing known locations of the **Hamersley Lepidium**, as seen in Annexure 1 during **construction** and **operation.**	Compliant	Vehicles, machinery and equipment did not access known locations of Hamersley lepidium during the report period. The Yandicoogina ground disturbance permitting and approvals request systems include an avoidance layer in the GIS which covers known locations of Hamersley lepidium as recorded in Annexure 1 of EPBC 2011/5815. This system highlights the areas that vehicles, machinery and equipment are prevented from accessing or disturbing in any way.

Condition Number	Condition	Compliance status	Evidence/Comments
8	The person taking the action must implement measures to prevent the spread or establishment of feral animal species populations within the **project area** in a manner that is sympathetic with the conservation of **EPBC Act listed threatened species**. Measures must include, but not necessarily be limited to: a) appropriate waste management associated with staff amenities, **construction** camps and material/equipment depots; b) a control program which is consistent with current national guidelines for pest control; and c) annual monitoring, reporting and evaluation of the measures.	Compliant	Measures have been undertaken to prevent spread or further establishment of feral animal species. Appropriate waste management has been implemented to ensure the project infrastructure and accommodation facilities do not encourage or allow the establishment of feral animal populations. Yandicoogina manages landfill facilities in accordance with the *Environmental Protection (Rural Landfill) Regulations 2002* and Iron Ore (WA) Non-mineral Waste Management Work Practice (our ref: RTIO-HSE-0010849) and the Waste Management Treatment, Storage and Disposal Guidelines (our ref: RTIO-HSE-0011578). Control programs for feral animals have been implemented in line with the Yandicoogina Feral Animal Management Plan (our ref: RTIO-HSE-0187214). Feral animal sightings and trapping activities are recorded in the Pilbara Ops feral animal control datasheet (our ref: RTIO-HSE-0230450). In the reporting period 4 cats were trapped and euthanized.

Condition Number	Condition	Compliance status	Evidence/Comments
9	The person taking the action must implement measures to prevent the spread or establishment of invasive weeds within the **project area** in a manner that is sympathetic with the conservation of **EPBC Act listed threatened species**. Measures must include, but not necessarily be limited to: a) baseline surveys and Geographical Information System mapping of target weed species, as determined by a **suitably qualified expert**; b) a targeted control program; c) weed hygiene measures for vehicles and mining equipment and machinery; and d) annual monitoring, reporting and evaluation of the measures identified in conditions 9) a) to c).	Compliant	Yandicoogina Weed Monitoring Plan was established in 2013 (our ref: RTIO-HSE-0188629) with a baseline weed survey completed. Weed mapping has been included as a layer within the on-site GIS and includes location of weeds found during surveys and timing and location of weed management activities. All machinery and equipment brought to site complete weed hygiene processes to prevent the introduction and spread of weeds as outlined in RTIO Equipment hygiene inspection procedure (our ref: RTIO-HSE-0036005). Targeted weed control activities were implemented within the project area in the reporting period.
10	The person taking the action must implement measures to prevent and/or control the spread of fires caused by any component of **construction** and **operation**.	Compliant	Detailed measures to prevent the starting of fires on site as outlined within the Rio Tinto Iron Ore Hot Work Safety Work Practice (our ref: RTIO-HSE-0049936). Measures to control and prevent the spread of any fires are detailed in the RTIO Iron Ore Bushfire Management Plan (our ref: RTIO-HSE-0335487).
11	In the event the person taking the action becomes aware of new information regarding the presence of any **EPBC Act listed threatened species** within the **development footprint**, that information must be reported to the **Minister** within seven business days of becoming aware of the new information.	Not applicable	No EPBC Act listed threatened species were sighted within the development footprint during the reporting period. Yandi_EPBC_National Matters of Environmental Significance Register (our ref: RTIO-HSE-0163656).

Condition Number	Condition	Compliance status	Evidence/Comments
12	The person taking the action must implement measures to minimise potential impacts from **dewatering** and discharge of surplus water on habitat for the **Northern Quoll** and **Pilbara Olive Python** along **Marillana Creek** and **Weeli Wolli Creek**, both in the dewatering and surplus water discharge impact areas. Measures must include, but not necessarily be limited to: a) baseline data surveys to be undertaken prior to **dewatering** and the discharge of surplus water, for **Northern Quoll** and **Pilbara Olive Python** habitat, including vegetation abundance, health, foliage cover and diversity; b) appropriate monitoring (including annual surveys) to detect changes, occurring as a result of the action, to **Northern Quoll** and **Pilbara Olive Python** habitat, including vegetation abundance, health, foliage cover and diversity; c) thresholds appropriate for the changes determined for condition 12) b) that establish when the action is resulting in degradation of habitat taking into consideration climatic variability, seasonal variation and discharge volumes from other relevant mines; d) contingency measures to be implemented, should the thresholds identified in condition 12) c) be exceeded as a result of the action, for addressing current and future exceedances and remediation of habitat degraded by dewatering and discharge activities; e) protocols for reporting to the **Minister** within seven days if the thresholds developed for condition 12) c) are exceeded, within 30 days for contingency measures implemented and within 6 months on the success the contingency measures.	Compliant	The potential impacts from dewatering and discharge of surface water on habitat for the Northern Quoll and Pilbara Olive Python along Marillana Creek and Weeli Wolli Creek, both in the dewatering and surplus water discharge impact areas have been identified and outlined within the Water and Discharge Monitoring and Management Plan, and Vegetation and Groundwater Dependent Ecosystems Monitoring and Management Plan (our ref: RTIO-HSE-165556). These plans also outline the environmental performance objectives and the management measures to minimise these potential impacts. Ongoing implementation of these plans during the project demonstrates compliance with this condition. Management activities and monitoring as per the plan were continued during the reporting period. Thresholds were not exceeded in the reporting period therefore contingency measures were not implemented and reporting to the Minister was not required.

Condition Number	Condition	Compliance status	Evidence/Comments
13	The person taking the action must rehabilitate all potentially suitable habitat for **EPBC Act listed threatened species** that is **disturbed** during **construction** and **operation**. The rehabilitation must be developed in consultation with a **suitably qualified expert** and must include, but not necessarily be limited to: a) baseline data of the characteristics of the pre-mining ecosystems within the **development footprint**; b) use of plant species of local provenance that are compatible with land system units that provide suitable habitat for **EPBC Act listed threatened species**; and c) monitoring and evaluation annually for three years or until establishment.	Compliant	The Yandicoogina Mine Closure Plan (our ref: RTIO-HSE-0208486) outlines the planned rehabilitation for these and other habitat areas that have been disturbed during construction and operations. Baseline data has been collected prior to disturbance to inform rehabilitation activities, and monitoring requirements are included within the closure plan. Rehabilitation trials are undertaken regularly with the results informing closure planning activities and rehabilitation measures. No suitable areas were identified in the reporting period for progressive rehabilitation within the project area however progressive backfilling continued in the Junction South West and Junction South East pits.
14	To compensate for the residual impacts of the action and for the better protection and long-term conservation of the **Northern Quoll** and **Pilbara Olive Python**, a Threatened Species Offset Plan (TSOP) must be submitted to the **Minister** for approval. The TSOP must include, but not necessarily be limited to: a) a contribution of no less than $3,000,000 (GST exclusive) to fund, extend or expand a land management program within the Pilbara bioregion for a period of no less than five years; b) details of measures to control and/or manage, for the benefit of the **Northern Quoll** and **Pilbara Olive Python**: i. introduced predators; ii. feral herbivores; iii. wild fires; and iv. invasive weeds. c) for each threat identified in condition 14) b), the TSOP must define: i. how the control/management measures are expected to benefit the **Northern Quoll** and **Pilbara Olive Python**; ii. details of the location and area of land to be managed which must be mapped and provided to the **department** in a **shapefile(s)**;	Compliant	The Yandicoogina Threatened Species Offset Plan (TSOP) (our ref: RTIO-HSE-0274440) was submitted to DoE for approval on 23 December 2014 (our ref: RTIO-HSE-0245553). The TSOP (V2) was subsequently approved by the Minister on 5 March 2015 (DoE ref: 2011/5815, our ref: RTIO-HSE-0275796). Further adjustments to the plan, to remove the requirements for Pilbara Olive Python abundance monitoring, fire management and weed monitoring to focus efforts on the introduced predator control program for the Northern Quolls were submitted to DoE 10 May 2017 (our ref: RTIO-HSE-0308684) and were accepted by DoE on 30 May 2017 (our ref: RTIO-CR-0260147). Ongoing implementation of the plan has occurred with $3,000,038.60 spent to the end of 2020. See Appendix 1 of this report for the TSOP Compliance Report.

Condition Number	Condition	Compliance status	Evidence/Comments
	iii. details of methodology, timing, frequency and intensity (effort) of management measures; iv. responsibility for management measures; v. details of how the management actions identified for condition 14) b) will be undertaken in a manner that is sympathetic with the conservation of other relevant threatened species listed under the **EPBC Act** known to occur in the area identified under 14) c) ii). d) details of a monitoring program, including but not necessarily limited to: i. methodology, timing, frequency, scope and survey effort for/of monitoring; ii. baseline surveys of the area to be managed; iii. monitoring during and post land management actions to determine the effectiveness of land management actions; iv. performance indicators, which will determine the effectiveness of the land management program; and v. measures to make the results of the monitoring made publically available. The TSOP must be submitted to the **Minister** for approval by 31 December 2014. Should the TSOP be approved then the approved TSOP must be implemented.		
15	Documentary evidence must be submitted to the **department** showing that payments of the total amount required in condition 14) a) have been made to the person(s) responsible for implementation of the land management program within 18 months of the date of approval of the TSOP.	Compliant	A biodiversity offset fund has been established with $3 million deposited into the trust account on 18 February 2014. TSOP approved by the Minister on 5 March 2015 (DoE ref: 2011/5815, our ref: RTIO-HSE-0275796).
16	Annually on 30 April, after **commencement** of the action, a report must be submitted to the **Minister** detailing how condition 14) is, or has been, met including: a) whether the timeframes for undertaking the management actions identified in condition 14) c) and d) have been met; and b) whether the performance indicators required for condition 14) c) have been met.	Compliant	2020 compliance against this condition provided by the submission of the 2019 EPBC compliance report on 30 April 2020 (our ref: RTIO-HSE-0340856).

Condition Number	Condition	Compliance status	Evidence/Comments
17	Within 10 days after the **commencement** of the action, the person taking the action must advise the **Department** in writing of the actual date of **commencement.**	Compliant	Notice of project commencement was provided to DoE on 3 December 2012 (our ref: RTIO-HSE-0165415).
18	The person taking the action must maintain accurate records substantiating all activities associated with or relevant to the conditions of approval, including measures taken to implement the plans required by this approval, and make them available upon request to the **department**. Such records may be subject to audit by the **department** or an independent auditor in accordance with section 458 of the **EPBC Act**, or used to verify compliance with the conditions of approval. Summaries of audits will be posted on the **department's** website. The results of audits may also be publicised through the general media.	Compliant	Records associated with or relevant to the conditions of this approval are maintained within the Rio Tinto Iron Ore Document Management System and are available upon request. No requests for information were received from and no audits were conducted by the DoE during the reporting period.
19	Annually on 30 April, after **commencement** of the action, the person taking the action must publish a report on their website addressing compliance with each of the conditions of this approval, including implementation of any management plans as specified in the conditions. Documentary evidence providing proof of the date of publication and non-compliance with any of the conditions of this approval must be provided to the **department** at the same time as the compliance report is published.	Compliant	Annual reports as published on the Rio Tinto website and provided to DoE at the time of publication. The 2019 annual compliance report (our ref: RTIO-HSE-0340856) was published on 30 April 2020. Reports available at: https://www.riotinto.com/-/media/Content/Documents/Operations/Pilbara/RT-Pilbara-Yandicoogina-EPBC-compliance-report-2019.pdf?rev=a08a0689f43240229d52b1cbb1ac7d0d
20	Upon the direction of the **Minister**, the person taking the action must ensure that an independent audit of compliance with the conditions of approval is conducted and a report submitted to the **Minister**. The independent auditor must be approved by the **Minister** prior to the commencement of the audit. Audit criteria must be agreed to by the **Minister** and the audit report must address the criteria to the satisfaction of the **Minister**.	Not applicable	No directions were received from the Minister during the reporting period.

Condition Number	Condition	Compliance status	Evidence/Comments
21	If the person taking the action wishes to carry out any activity otherwise than in accordance with the plan(s) as specified in the conditions, the person taking the action must submit to the **department** for the **Minister's** written approval a revised version of that plan(s). The varied activity shall not commence until the **Minister** has approved the varied plan(s) in writing. The **Minister** will not approve a varied plan(s) unless the revised plan(s) would result in an equivalent or improved environmental outcome over time. If the **Minister** approves the revised plan(s), that plan(s) must be implemented in place of the plan(s) originally approved.	Not applicable	No variations were requested during the reporting period.
22	If the **Minister** believes that it is necessary or convenient for the better protection of listed threatened species and communities to do so, the **Minister** may request that the person taking the action make specified revisions to the plan(s) specified in the conditions and submit the revised plan(s) for the **Minister's** written approval. The person taking the action must comply with any such request. The revised approved plan(s) must be implemented. Unless the **Minister** has approved the revised plan(s), then the person taking the action must continue to implement the plan(s) originally approved, as specified in the conditions.	Not applicable	No requests were received from the Minister during the report period.
23	If, at any time after five (5) years from the date of this approval, the person taking the action has not **substantially commenced** the action, then the person taking the action must not **substantially commence** the action without the written agreement of the **Minister**.	Not applicable	Notice of project commencement was provided to DoE on 3 December 2012 (our ref: RTIO-HSE-0165415). Project substantially commenced in 2013.
24	Unless otherwise agreed to in writing by the **Minister**, the person taking the action must publish all plan(s) referred to in these conditions of approval on their website. Each plan must be published on the website within 1 month of being approved.	Compliant	Threatened Species Offset Plan as required by Condition 14 published on the Rio Tinto website and accessible via the link below: https://www.riotinto.com/-/media/Content/Documents/Operations/Pilbara/RT-Pilbara-Threatened-species-offset-plan.pdf?rev=8915135e7b4b40e8af4ea297deb1b68a

3 New environmental risks

There are no new environmental risks that have become apparent during the reporting period.

4 Declaration of accuracy

In making this declaration, I am aware that sections 490 and 491 of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) make it an offence in certain circumstances to knowingly provide false or misleading information or documents. The offence is punishable on conviction by imprisonment or a fine, or both. I declare that all the information and documentation supporting this compliance report is true and correct in every particular. I am authorised to bind the approval holder to this declaration and that I have no knowledge of that authorisation being revoked at the time of making this declaration.

Signed:

Full name:

Position

Organisation:

Date:

5 Appendices

Appendix 1: Yandicoogina JSW and Oxbow Iron Ore Project TSOP 2020 Compliance Report

Yandicoogina JSW and Oxbow Iron Ore Project

TSOP 2020 Compliance Report

EPBC 2011/5815 Condition 14: Threatened Species Offset Plan

MS 1038 Condition 7: Offsets

April 2020

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RTIO-HSE-0349979

Disclaimer and Limitation

This report has been prepared by Rio Tinto Iron Ore (**Rio Tinto**), on behalf of Hamersley Iron-Yandi Pty Limited (the **Proponent**), specifically for the Yandicoogina JSW and Oxbow Project. Neither the report nor its contents may be referred to without the express approval of Rio Tinto, unless the report has been released for referral and assessment of proposals.

Document Status					
Rev	**Author**	**Reviewer/s**	**Date**	**Approved for Issue**	
				To Whom	**Date**
1	R. Vieira	S. Rusbridge	9 February 2021	OEPA/DoE	April 2021

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APPENDICES

CONTEXT

The Yandicoogina Junction South West and Oxbow Project is subject to both Western Australian State and Commonwealth environmental approval via Ministerial Statement 1038 and EPBC Decision Notice 2011/5815, both of which include offset conditions:

- Condition 7-1 of MS 1038 requires the contribution of $3M AUD towards an offset for clearing completed under MS 914.

- Condition 7-3 of MS 1038 requires the contribution of funds for the clearing of 'Good to Excellent' condition vegetation towards an offset, to be distributed via conditions 7-5, 7-6 and 7-7.

- Condition 14 of EPBC 2011/5815 requires the submission of a Threatened Species Offset Plan (**TSOP**) which includes a contribution of no less than $3M over five years (Condition 14a).

Both agencies have agreed that the State offset requirement could be used to fund the development of the Commonwealth required TSOP.

Specifically, the TSOP is required to offset significant residual impacts to biodiversity and to two Matters of National Environmental Significance: the northern quoll and the Pilbara olive python; by managing threatening processes, identified in Condition 14b EPBC 2011/5815 as:

1. introduced predators;

2. introduced herbivores;

3. wildfire; and

4. weeds.

The TSOP (Rio Tinto 2015; RTIO-HSE-0274440) was approved by the Office of the Environmental Protection Authority on 19 January 2015 (RTIO-HSE-0248720) and by the Department of the Environment (DoE) on 5 March 2015 (RTIO-HSE-0275796).

Management actions have been prioritised following consultation with the Department of Biodiversity, Conservation and Attractions (DBCA) and a Biodiversity Offsets Advisory Panel comprising independent experts. On their advice, the TSOP prioritises resources and expenditure towards the delivery of a landscape-scale Introduced Predator Control Program (Action #1) and associated monitoring. As a result, a relatively small proportion of the overall funds and resources are directed towards managing the remaining three actions on introduced herbivores, wildfire and invasive weeds. In 2017 it was agreed with the DoE that as a part of adaptive management, the best environment outcomes would be to concentrate funding on the Predator Control Program (*Eradicat)* and remove the requirement to complete further weed monitoring and a fire management plan as it is unlikely to result in improved environmental outcomes for the northern quoll and Pilbara olive python.

The Introduced Predator Control Program was designed collaboratively by the DBCA, Rio Tinto (on behalf of the Proponent, Hamersley Iron-Yandi Pty Limited) and the Biodiversity Offsets Advisory Panel and commenced in 2015 as the Northern Quoll *Eradicat*® Cat Bait Uptake and Survivorship Study. The aim of the Survivorship Study was to determine the impact of feral cat baiting on northern quolls and thus inform the scope of the operational predator control program for subsequent years. The survivorship study was approved by the Parks and Wildlife Animal Ethics Committee (Approval # 2014/11).

ANNUAL REPORTING

The table below highlights the progress of all projects in the TSOP in 2020.

Table 1: TSOP project status 2020

Management program	Action	Details of work progressed	Status / Comments
Introduced Predator Control Program	2	Eradicat® baiting program	Completed.
		Feral cat monitoring program	Completed.
		Northern quoll monitoring program	Completed.
Introduced Herbivore Management	3	Mustering of cattle across the Yarraloola land management area (Yarraloola LMA), inclusive of the section of unallocated Crown land to the east of Yarraloola Station.	Completed.
		Vegetation cover change assessment on Yarraloola and Red Hill.	Completed. Appendix 3: Vegetation cover change assessment on Yarraloola and Red Hill
Fire Management	5	Annual desktop fire regime monitoring: Yarraloola and Red Hill.	Completed. Appendix 1: Annual desktop fire regime monitoring Yarraloola Appendix 2: Annual desktop fire regime monitoring Red Hill
Weed Management	6	Vegetation cover change assessment on Yarraloola and Red Hill.	Completed. Appendix 3: Vegetation cover change assessment on Yarraloola and Red Hill
Offset Funds		Condition 14a and 15 of EPBC 2011/5815 and Condition 7 of MS1038	Completed.

1 INTRODUCED PREDATOR CONTROL

GOAL: *To enhance northern quoll and Pilbara olive python populations (and populations of other native fauna) and their habitat through a reduction in introduced predators (principally feral cats but also foxes and wild dogs) within the LMA*.

1.1 ACTION 1: NORTHERN QUOLL SURVIVORSHIP STUDY

1.1.1 Northern quoll Eradicat cat bait uptake and survivorship study

The 2015 Northern quoll bait uptake and survivorship study found that there was no observable impact from the Eradicat baiting trial on local northern quoll populations and concluded that baiting with Eradicat in winter is unlikely to have a detrimental impact on northern quolls in the Yarraloola Land Management Area (LMA). As such, the Introduced Predator Control Program (proposed as Action 2 in the TSOP) was implemented starting in 2016 across the LMA.

This action was closed after completion of the 2015 trial.

1.2 ACTION 2: INTRODUCED PREDATOR CONTROL PROGRAM

The Introduced Predator Control (IPC) program was completed in July each year from 2016 to 2019. In each year of the program, a broad-scale aerial baiting program (>140,000ha) using Eradicat baits was conducted in the Yarraloola LMA. The effectiveness of the baiting program in reducing feral cat populations was assessed using camera trap monitoring, which was supplemented by a radiotelemetry study in 2018 and 2019. Potential impacts to non-target species and benefits of the broad scale baiting program on northern quoll populations were assessed by comparing their abundance, survivorship and demographics over time between the treatment (baited) site at Yarraloola and an unbaited reference site at Red Hill. While attempts were made early in the program to monitor Pilbara olive python populations in response to the baiting program, this was discontinued in 2017 due to the difficulties in monitoring this species.

A key outcome of the IPC program was a significant and sustained reduction in the relative abundance of feral cats after baiting at Yarraloola relative to Red Hill. In all years there were less detections of feral cats after baiting at Yarraloola (Figure 1). While cat detections also decreased pre- and post-baiting each year at the unbaited site Red Hill in 2016, 2017 and 2019, there was no sustained decrease observed over the four year program. This indicates that while there are natural fluctuations in cat detections over time, the baiting program successfully reduced overall cat numbers at Yarraloola.

The radiotracking study in 2018 and 2019 broadly supports the results of the camera trap monitoring. Nineteen cats (12 male, 7 female) were trapped and fitted with radiotracking collars at Yarraloola. Mortality of six cats could definitively be attributed to baiting; in all cases death occurred within 3 weeks of a bait deployment. At Red Hill, while only three cats were fitted with radiotracking collars, all were recorded as alive approximately 16 months after initial capture.

In all years of the IPC program, detection rates of quolls were higher at Yarraloola than at Red Hill, both before and after each annual baiting program (Figure 1). While not statistically significant, a general trend of an overall increase in quoll detections between 2016 and 2019 was observed pre-baiting at Yarraloola but not at Red Hill. In all years, quoll detections at Red Hill were lower in the post-baiting monitoring than in pre-baiting; this was also observed at Yarraloola in 2018 and 2019. Such a decrease in quoll numbers can be partially explained due to natural die-off of male quolls post-breeding. The magnitude of this difference between the two sites may be due to a reduced predation risk to male quolls at Yarraloola through the lower abundance of feral cats. Cage trapping of quolls at the two sites approximately 2 months post-baiting also found higher numbers of quolls at Yarraloola than Red Hill in all years.

Additional analysis undertaken in 2020 (Palmer *et al, in prep.*) showed that the cumulative number of camera sites where quolls were detected increased at both sites between 2016 and 2019; however,

the cumulative increase from 2018 onwards was greater at Yarraloola than at the unbaited reference site. This indicates a greater spatial distribution of quoll detections at the treatment site over time.

Based on the results of the cat and quoll monitoring programs, broad scale baiting with Eradicat across Yarraloola can be considered successful and having a positive impact on quoll populations. This action was reported to DoEE as complete in all annual reports against EPBC 2011/5815 Condition 14; **Action 2 is therefore considered complete**.

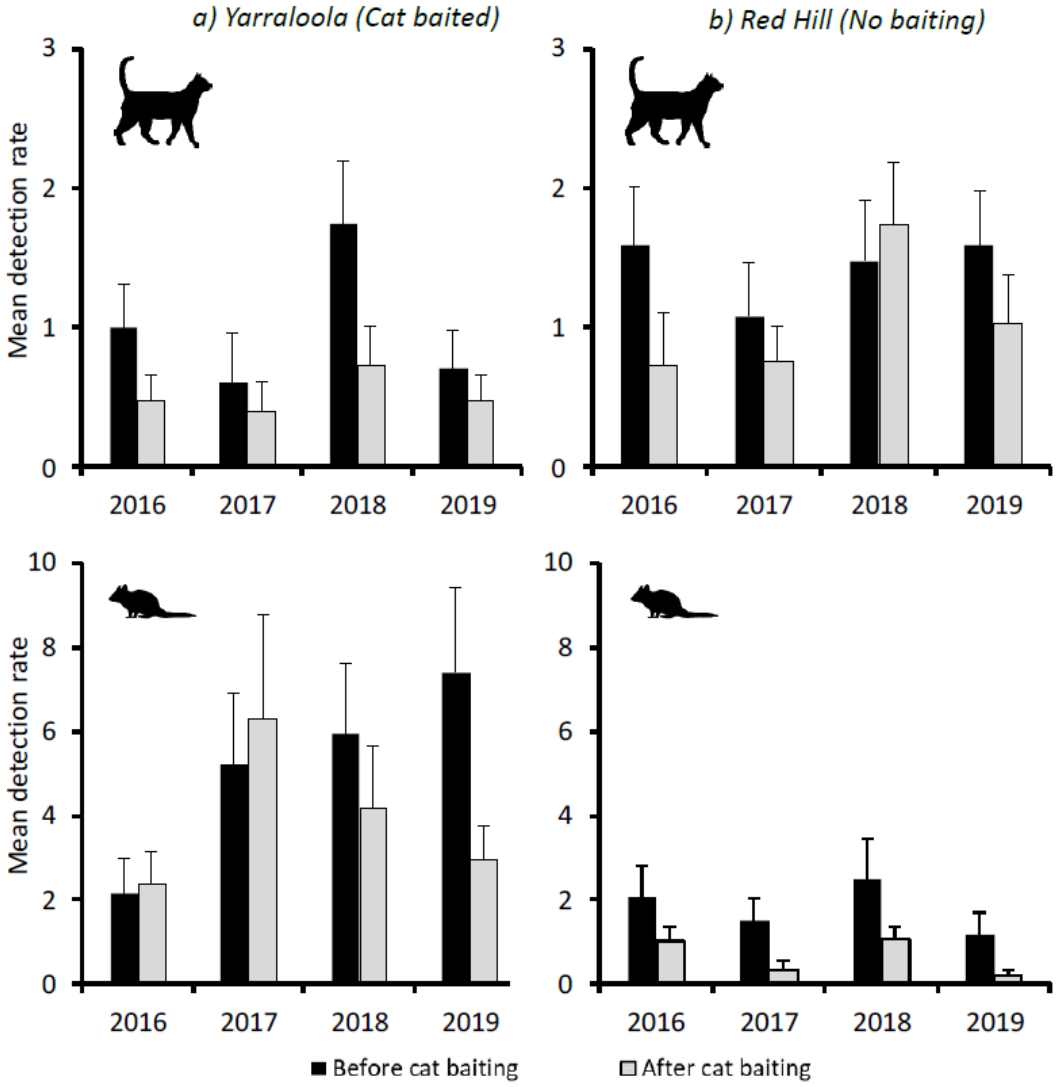

Figure 1: Mean detection rate (number of detections per 100 camera trap nights per camera trap site) of feral cats and northern quolls at a) Baited site - Yarraloola and b) Unbaited site - Red Hill, before and after the winter baiting program from 2016 to 2019. (Figure from DBCA 2020).

2 INTRODUCED HERBIVORE MANAGEMENT

Goal: *To enhance northern quoll and Pilbara olive python habitat through a reduction in feral cattle within the LMA.*

2.1 ACTION 3: MUSTER TO REMOVE FERAL CATTLE ACROSS THE LMA

Mustering was completed in all years at Yarraloola from 2015 – 2019. Mustering also included some areas of unallocated crown land to the southeast of Yarraloola Station. In all years, no cull of feral cattle was undertaken; cattle were either released back to the station if part of the Yarraloola stock, or otherwise removed to market. One of the key indicators for success of the mustering program was a decreasing trend in feral herbivore activity relative to baseline values; however, this is difficult to determine due to the relatively low area covered in the 2015 muster (~3,500ha). More cattle were mustered in all following years; however, the area was significantly larger (~103,000ha).

Land condition over the same period (Figure 2), as determined by analysis of aerial imagery, was relatively stable in both the Yarraloola POP/NQ habitat areas and the broader LMA, but a decrease in condition was recorded in 2018 and 2019. Similar trends were also observed at the Red Hill reference site over the same period. While mustering was successful in terms of removing significant numbers of herbivores from the LMA, the similarity in results between control and reference sites indicates that there are likely to be other factors such as fire (increased in 2019) and rainfall (low in 2019) which drive changes in vegetation condition. It is difficult to correlate changes in land condition with the number of cattle mustered; this measure may therefore not be an appropriate indicator for the success or failure of this action.

Based on annual removal of introduced herbivores in the LMA, this action could broadly be considered a success, but for future programs more suitable indicators of land condition, factoring in environmental variation should be considered.

This action was reported to DoEE as complete in all annual reports against EPBC 2011/5815 Condition 14; **Action 3 is therefore considered complete**.

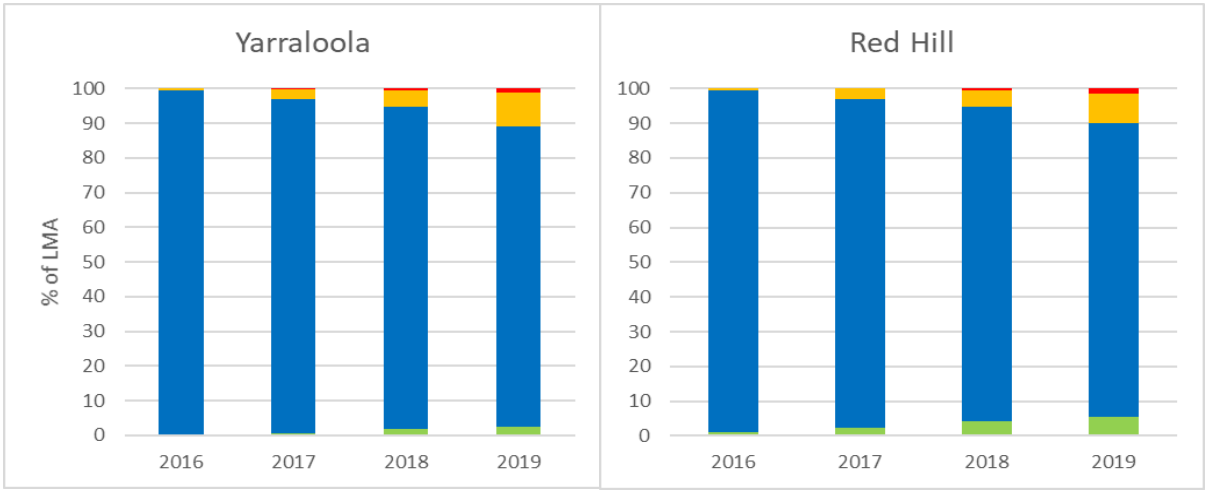

Figure 2: Change in vegetation condition (as a percentage of LMA) per year during TSOP at Yarraloola and Red Hill. (Key: Stable; Large increase; Moderate increase; Moderate decrease; Large decrease)

2.2 ACTION 4: CULL OF FERAL INTRODUCED HERBIVORES

No cull of feral herbivores was undertaken in any year of the program, as no feral cattle were encountered during musters, and no other feral herbivore species were observed in the project area.

As noted previously, any cattle mustered were either released back to the land or removed to market. This approach was accepted by DoEE in 2017. A key indicator for success of this action was a decreasing trend in feral herbivore abundance, but no feral herbivores were encountered in any year of the program.

Another key indicator (increasing trend in land condition in areas of moderate to good pasture potential) has similar limitations as those outlined for Action 3, i.e. other factors such as fire and rainfall are likely to drive changes in vegetation condition. Given that no feral herbivores were recorded in the project area it is not possible to draw any conclusions about land condition relative to this Action. Again, for future programs, more suitable indicators of land condition should be considered.

This action was reported to DoEE as complete in all annual reports against EPBC 2011/5815 Condition 14; **Action 4 is therefore considered complete**.

3 WILDFIRE MANAGEMENT

Goal: *To monitor and, where necessary, manage fire in the LMA in a manner that maintains or enhances its current relatively benign impacts on northern quolls, Pilbara olive pythons and their habitats.*

3.1 ACTION 5: FIRE REGIME MONITORING

A desktop review of aerial imagery was conducted each year to determine percentage area burnt across the Yarraloola and Red Hill LMAs, as well as within the mapped NQ/POP habitat areas at each site. There was a high degree of variation in areas burnt each year at both sites (Figure 3). At Red Hill, a higher proportion of the NQ/POP habitat was burned compared to the entire LMA in 2015 and 2016.

Significant areas of the Yarraloola LMA burned in 2018 compared to other years, both overall (22%) and within the NQ/POP habitat area (24%), which may have influenced 2019 fauna monitoring results. While this represents the highest percentage area burnt during TSOP, it is within the range of observations from historical data (Figure 3; 2001: 28% total, 21% habitat; 2006: 26% total, 33% habitat; 2014: 12% total, 24% habitat).

Fire data was reviewed in 2017 to determine whether a fire management plan was required for the remainder of the TSOP; however, the review identified that that no management plan was necessary.

This approach was supported by DoEE; **Action 5 is therefore considered complete.**

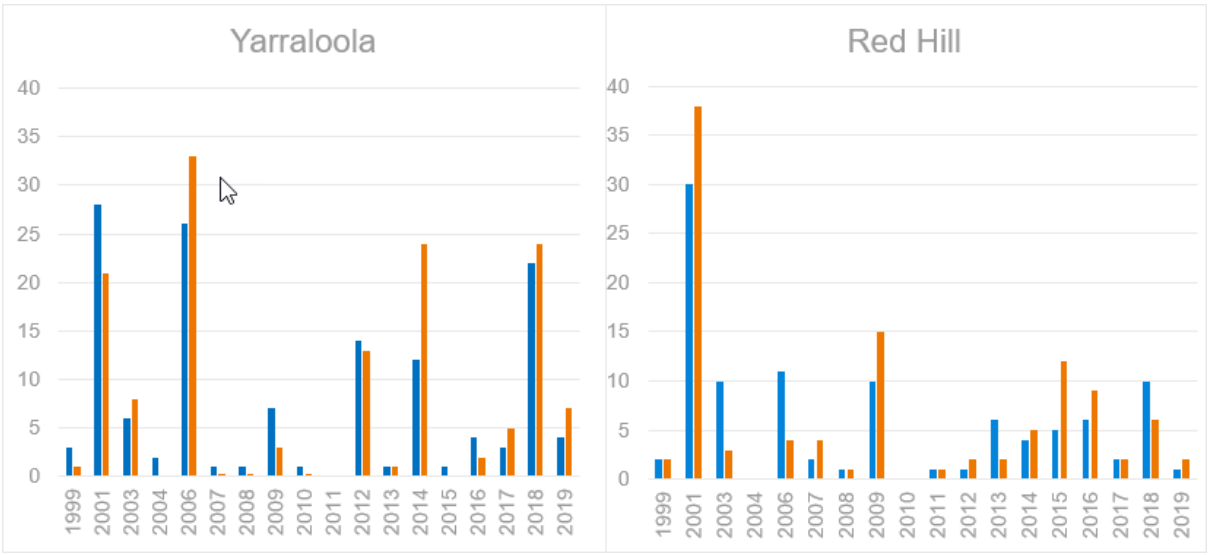

Figure 3: Percentage area burned over the entire LMA ( ) and in NQ/POP habitat ( ) at Yarraloola and Red Hill between 1999 and 2019.

4 WEED CONTROL

Goal: *To understand the diversity and distribution of weeds within the LMA and the potential implications for the management of northern quoll and Pilbara olive python habitat.*

4.1 ACTION 6: MONITORING OF WEEDS OF LAND MANAGEMENT AREA

The TSOP initially proposed weed monitoring as part of the suite of land condition parameters, with review in Year 3 to determine whether a weed action plan was required for the LMA. No weeds of national significance were found in 2015 and 2016 surveys. The 2017 review found that further weed monitoring or control was unlikely to result in improved outcomes for northern quoll populations, and recommended continuation of land condition monitoring as outlined under Actions 3 and 4 be used to meet the requirements of Action 6.

As this approach was supported by DoEE; **Action 6 is considered complete**.

5 TSOP EXPENDITURE

In accordance with Condition 15 of EPBC 2011/5815 and Condition 7 of MS 1038, the Proponent provides the following breakdown of expenditure regarding the implementation of the TSOP over 2014 – 2018.

Table 2: Annual and total expenditure for the TSOP project

Itemised Expenses	2014 expenditure	2015 expenditure	2016 expenditure	2017 expenditure	2018 expenditure	2019 expenditure	2020 expenditure	Total
RTIO employee related costs	$258.50	$490.00	$0	$0	$0	$0	$0	**$748.5**
Contractors	$1,109.09	$110,031.33	$25,427.45	$0	$1,950.00	$0	$0	**$138,517.87**
External Services	$135,420.00	$204,970.00[1]	$604,803.13	$419,907.05	$654,899.17	$552,788.95	$68,178.73[2]	**$2,640,967.03**
Travel and related expenses	$3,951.62	$48,922.64	$44,301.86	$12,554.12	$60,917.89	$42,256.15	$0	**$212,904.28**
Other operating costs		$6,148.80	$612.12	$140	$0	$0	$0	**$6,900.92**
Total	**$140,739.21**	**$370,562.77**	**$675,144.56**	**$432,601.17**	**$717,767.06**	**$595,045.10**	**$68,178.73**	**$3,000,038.60**

Notes:

1 There was an incorrect accrual of $85,020 accounted for in previously reported 2015 External Services spend which has also been accounted in 2016's spend. Data has been corrected and total spend is correct in this report.

2 2020 spend includes costs of 2019 fire and vegetation condition reporting, additional funding to DBCA for preparation of manuscripts to support licensing of Eradicat bait, and field program to recover remaining radio collars.

Condition 14 of EPBC approval 2011/5815 required that the TSOP must include a contribution of no less than $3,000,000 (GST exclusive) to fund, extend or expand a land management program within the Pilbara bioregion for a period of no less than five years. Expenditure has been reported in annual compliance reports as referenced in Table 4; Total TSOP expenditure reported to end-2019 was $2,931,859.87.

Additional funds as outlined in Table 4 have been allocated in 2020 to complete further reporting and analysis of data collected during the program; total expenditure is now in excess of $3,000,000.

Allocation of project expenditure is therefore complete for closeout of TSOP.

6 APPENDICES

Appendix 1: Annual desktop fire regime monitoring Yarraloola

GOVERNMENT OF WESTERN AUSTRALIA

Department of **Biodiversity, Conservation and Attractions**

Yarraloola annual desktop fire regime monitoring: 2019

Version: 2

Approved by: Russell Palmer

Last Updated: 25/08/2020

Custodian: Department of Biodiversity, Conservation and Attractions

Review date:

Version number	Date approved	Approved by	Brief Description
1	5/08/2020	Russell Palmer	Minor edits, page numbering, page header
1	11/08/2020	Tessa Elvey, Jason Rossendell	Minor edits and formatting
2	25/08/2020	Tessa Elvey, Jason Rossendell	Formatting, additional land systems graphs added, minor edits

Yarraloola annual desktop fire regime monitoring: 2019

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[2]Senior Research Officer (Remote Sensing)

August 2020

GOVERNMENT OF WESTERN AUSTRALIA

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Please note: urls in this document which conclude a sentence are followed by a full point. If copying the url please do not include the full point.

Contents

Figures

Tables

Summary

This report addresses the tasks outlined in the document “Scope of Works - DPaW TSOP Fire Regime Monitoring 2019” and includes fire metrics over the Yarraloola Land Management Area (LMA) for the time period 1999 – 2019.

The fire metrics contained in this report are listed in Table 1.

Table 1 Fire metrics covered in the report for the period 1999 – 2019.

Metric	**Status**
Total area (ha) and proportion burned each year ▪ across entire study area ▪ within land system units ▪ within mapped NQ & POP habitat	Achieved

The project area known as the Yarraloola Land Management Area (LMA) is indicated in blue on Figure 1, and indicates the area subject to analysis, the LMA covers 163,214 hectares. In order to understand fires that occur close to or overlap this boundary a 10km buffer area for the provided vector mapping of the fires is delivered for map production use only. The composite land system mapping and fauna habitat areas used in the analysis have been supplied by Rio Tinto (2016_Yarraloola_LandSystems_exported_mga50 and Yarraloola_potential NQ & POP habitat FINAL_trans.shp).

For information on image processing, fire mapping and satellite imagery please see previous monitoring reports by Chapman and Zdunic (2016). Methodology describing the creation of the fire scar dataset will not be included in this update.

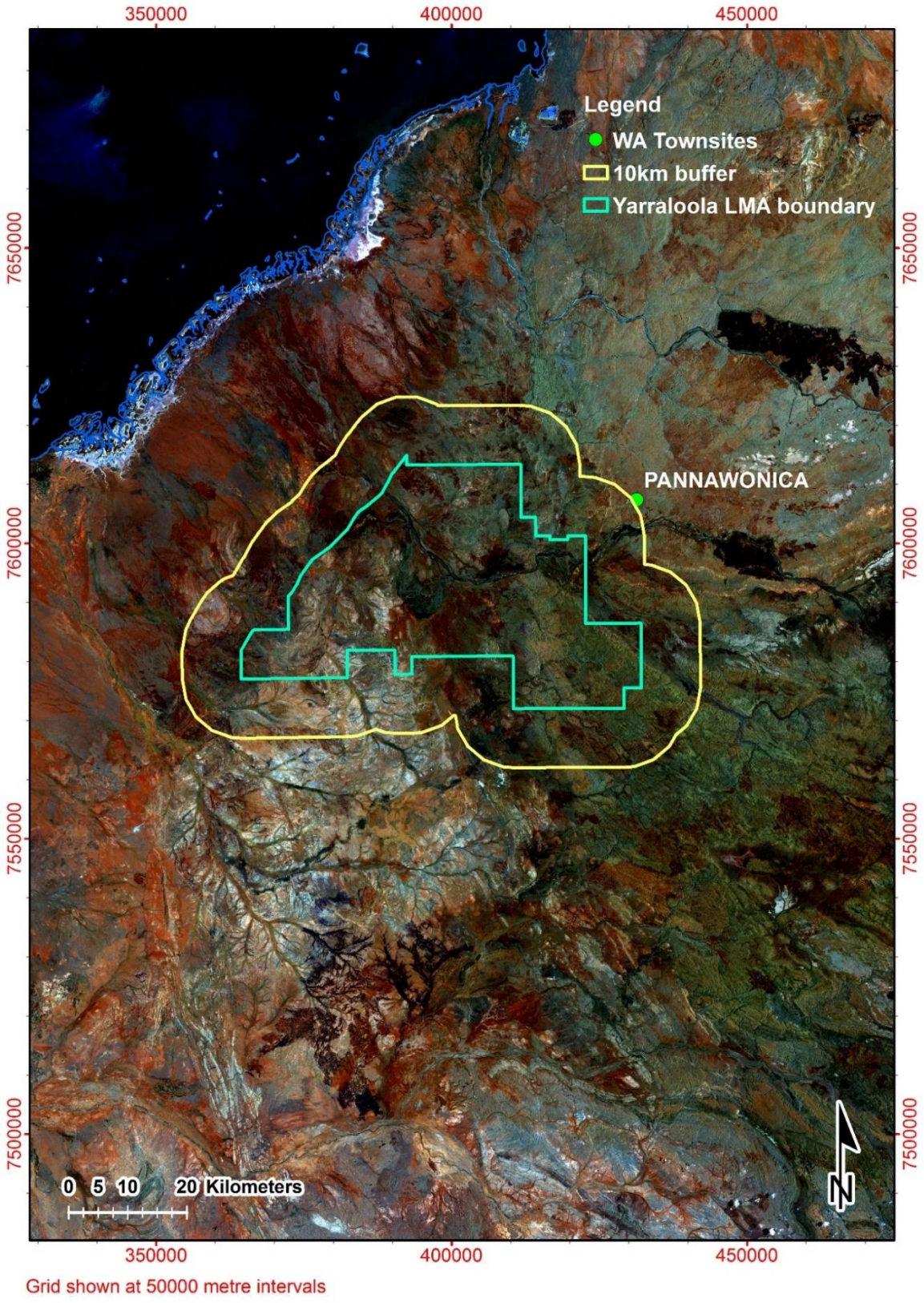

Figure 1 Yarraloola Land Management Area, the background image is a Landsat 8 satellite image.

1 Data

Fire metrics were calculated using a combination of datasets provided by Rio Tinto and the Department of Biodiversity, Conservation and Attractions. Table 2 displays the datasets used.

Table 2 Datasets used in the Yarraloola fire metric analysis.

Dataset	Source	Description
Yarra_Fire_Monitoring_Study_Area_exported.shp	Rio Tinto	Yarraloola LMA boundary
Yarra_Fire_Monitoring_Project_Area_trans.shp	Rio Tinto	Yarraloola LMA boundary
2016_Yarraloola_LandSystems_exported_mga50.shp	Rio Tinto	Land system boundaries
Yarraloola_potential NQ & POP habitat FINAL_trans.shp	Rio Tinto	Northern Quoll and Pilbara Olive Python habitat extent
Yarraloola Station_exported.shp	Rio Tinto	Yarraloola LMA boundary
Pilbara_fires_Z50_1999.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2001.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2003.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2004.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2006.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2007Oct.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2008.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2009.shp	DBCA	Fire scar boundaries
114075_2010-2011_FireScars.shp	DBCA	Fire scar boundaries
114075_2011-2012_FireScars.shp	DBCA	Fire scar boundaries
11475_2012-2013_FireScars.shp	DBCA	Fire scar boundaries
Fortescue_and_Offshore_Fires_2013_2014.shp	DBCA	Fire scar boundaries
Fortescue_River_Catchment_fire_mapping_2015.shp	DBCA	Fire scar boundaries
201516_Pilbara_Fire_Mapping_mga50.shp	DBCA	Fire scar boundaries
201617_114075_afed.shp	DBCA	Fire scar boundaries
114075_dec16_to_dec17_rio_2017_update.shp	DBCA	Fire scar boundaries
114075_160918_060119_mga50.shp	DBCA	Fire scar boundaries
Yarraloola_201920_fires_10kmbuffer.shp	DBCA	Fire scar boundaries

1.1 Land systems mapping

The land systems mapping dataset was provided by Rio Tinto. This dataset was used to calculate area-based statistics for land systems within the Yarraloola LMA. The total areas and the description for each Land system are listed in Table 3. Figure 2 displays a map of Yarraloola LMA and the supplied mapping.

Table 3 Land systems and area statements over the Yarraloola Land Management Area.

Land system ID	Description	Area (hectares)
NNT	Nanutarra Land System	23,623.19
SRK	Sherlock Land System	11,343.65
CPN	Capricorn Land System	11,146.45
RIV	River Land System	6,465.81
ROB	Robe Land System	13,055.07
BGD	Boolgeeda Land System	17,482.28
URY	Urandy Land System	12,728.45
STT	Stuart Land System	23,992.98
NEW	Newman Land System	32,332.09
ROC	Rocklea Land System	2,313.85
CAN	Cane Land System	1,843.26
KUM	Kumina Land System	662.55
MAL	Mallina Land System	1,746.83
MCK	McKay Land System	170.98
PED	Peedamulla Land System	4,306.59

1.2 Northern Quoll and Pilbara Olive Python boundary

An ESRI shapefile with the habitat extent of the Northern Quoll (NQ) and Pilbara Olive Python (POP) was provided by Rio Tinto. Mapped habitat for both NQ and POP is based on land system mapping (van Vreeswyk *et al.*, 2004) and represents a coarse estimate of available habitat within the LMA. The total area of the fauna habitat covers 65,665 hectares of Yarraloola LMA. Figure 2 displays a map of the fauna habitat within Yarraloola LMA. Throughout this document the habitat area for the fauna will be referred to as the NQ and POP habitat.

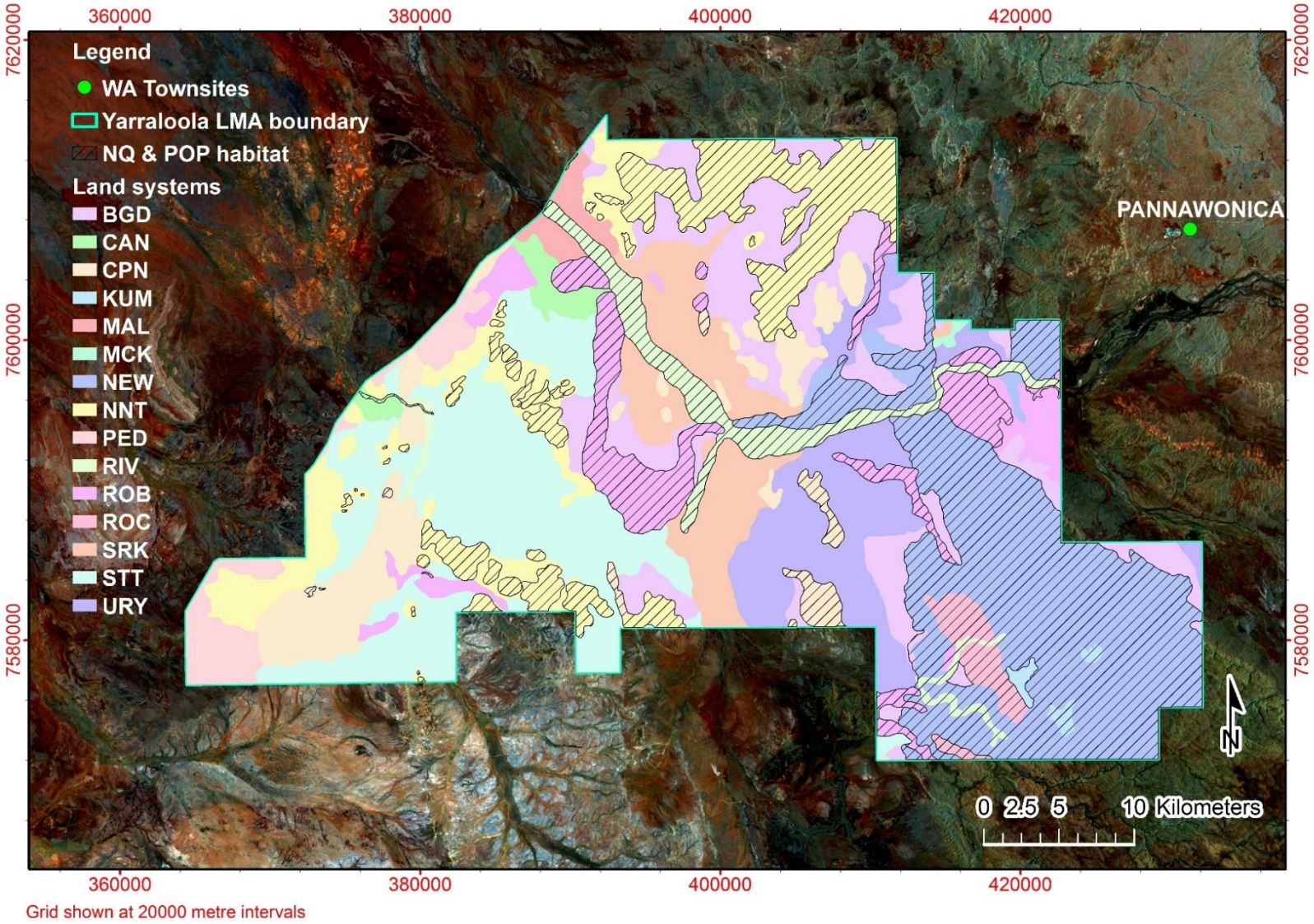

Figure 2 Yarraloola Land Management Area with land systems mapping and Northern Quoll and Pilbara Olive Python habitat boundary, the background image is a Landsat 8 satellite image.

2 Methodology

The methodology describes the calculation of the fire metric statistics.

2.1 Fire metrics

Metrics were derived from the fire scar datasets using ArcGIS 10.6.1. This software is geographic information systems software that allows the viewing, analysis and storage of spatial data.

2.1.1 Vector data cleaning

Fire scar vectors were examined for errors in the data, which might cause errors in the area statistics. Duplicate polygons can sometimes occur when the same fire is mapped more than once, this is more common around the edges of Landsat scene boundaries. To find duplicate polygons within each year of fire scar mapping the “Count Overlapping Polygons” toolbox in ArcGIS was used (Honeycutt, 2012). Duplicate polygons were then deleted. Part of the cleaning process was to ensure all data were in the same coordinate system and that all datasets had been repaired using the “Repair Geometry” tool in ArcGIS.

Once all the individual years of fire scar datasets were cleaned they were merged into one shapefile and clipped to the Yarraloola LMA 10km buffer shapefile using the “Clip” tool in ArcGIS. This dataset was further clipped to the Yarraloola LMA area of interest.

2.1.2 Graphing fire metrics

Graphs were produced using the statistical package R. This enables repeatability in the graphing as a script has been produced for each graph and annual updates require the latest data to be entered (R Core Team, 2017).

3 Results

The results address the fire metrics requested and listed in Table 1. The results are structured according to Table 4.

Table 4 Metrics and their associated graphs and tables.

Metric	**Category**	**Graphs/ tables**
3.1 Total area (ha) and proportion burned each year.	3.1.1 Across entire study area	Table 6 Figure 4 and Figure 5
	3.1.1 Within mapped NQ & POP habitat	Table 6 Figure 4 and Figure 5
	3.1.2 Within land systems	Table 7 and Table 8 Figure 6 and Figure 7 Alternative style graphs: Figure 8 and Figure 9 Individual land system graphs: Figures 10 - 24

To provide context of each variable across the Yarraloola LMA the area of the study site, POP and NQ habitat and land systems that fire metrics were calculated for are displayed in Table 5.

Table 5 Area statistics for each zone; area statements were used to calculate metrics based on these zones.

Zone	Total area (ha)	% of study area
Yarraloola LMA	163213.70	100
POP NQ Habitat	65,665.00	40.23
NNT	23,623.19	14.47
SRK	11,343.65	6.95
CPN	11,146.45	6.83
RIV	6,465.81	3.96
ROB	13,055.07	8.00
BGD	17,482.28	10.71
URY	12,728.45	7.80
STT	23,992.98	14.70
NEW	32,332.09	19.81
ROC	2,313.85	1.42
CAN	1,843.26	1.13
KUM	662.55	0.41
MAL	1,746.83	1.07
MCK	170.98	0.10
PED	4,306.59	2.64

3.1 Total area and proportion burned in each fire mapping year

The following statistics show total area burnt in hectares for each year of available fire mapping. A variety of graphs and tables are presented for each fire metric to allow for different options to be explored. Metrics calculated are provided as;

Total area (ha) and proportion burned each year:

- across the entire study area
- within mapped NQ and POP habitat
- within land systems

Fires that occurred during 2019 on Yarraloola and within 10km of the boundary are shown in Figure 3 below.

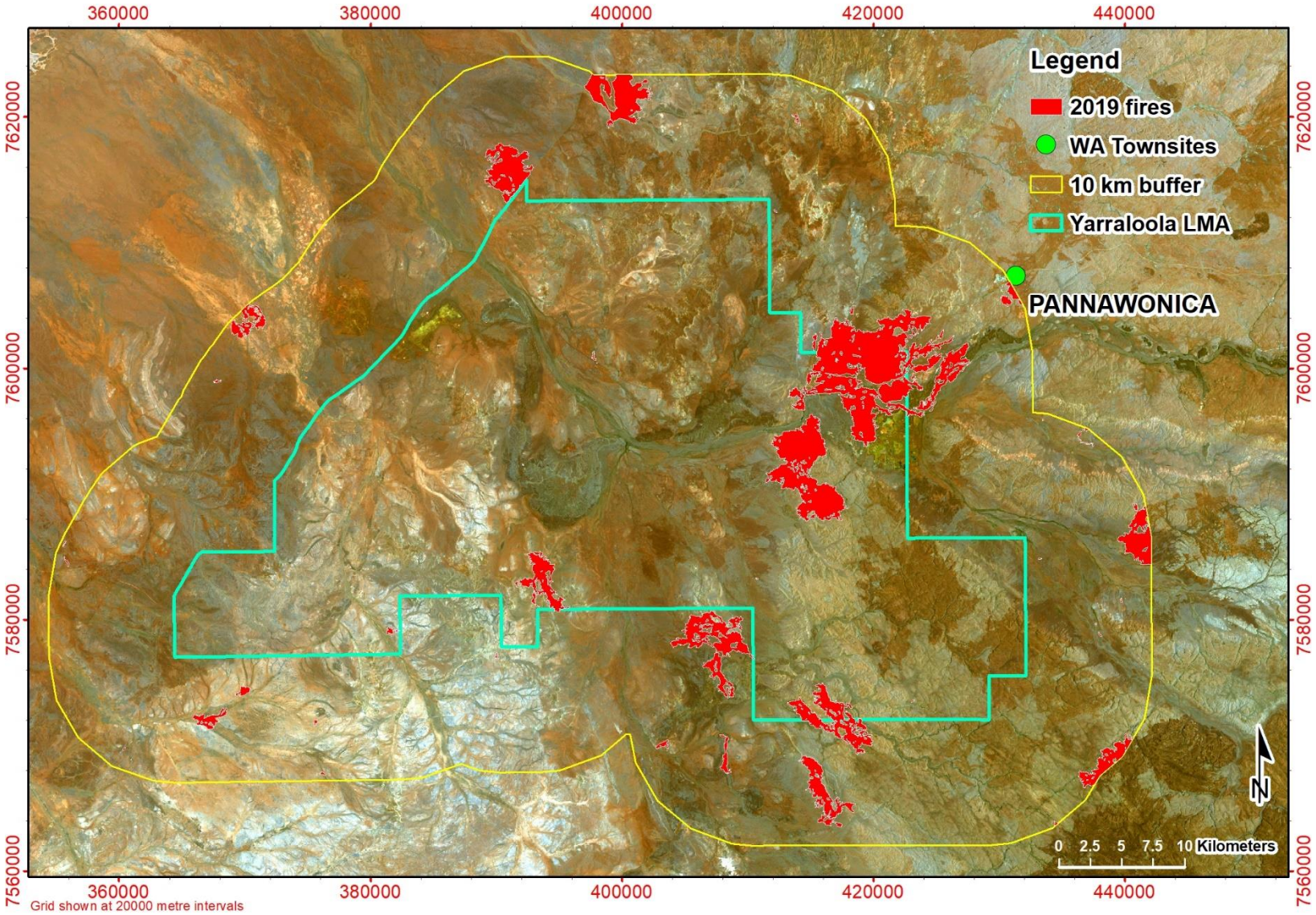

Figure 3: Fires which occurred on Yarraloola Station and within a 10km buffer during 2019, the background image is a Landsat 8 satellite image, the image date is 24th December 2019 and was used to map the 2019 fires.

3.1.1 Across Yarraloola LMA and mapped NQ and POP habitat

The NQ and POP habitat and total Yarraloola area metrics have been combined in both the tables and figures as the NQ and POP habitat is a subset of the total area and this reduces the number of tables, graphs and figures. Table 6 displays the total area of land mapped as burnt over Yarraloola and the NQ and POP habitat. The percentages based on these area figures are also displayed in Table 6. Graphs of the area statements are displayed in Figure 4 and percentages values are displayed in Figure 5.

Table 6 Total area and percentage of land burnt (ha) over Yarraloola LMA and NQ & POP habitat for each year of available fire mapping.

YEAR	1999	2001	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
TOTAL AREA BURNT (HA)	5,488	46,470	9,824	3,182	42,330	1,293	2,268	10,843	2,188	522	23,531	1,986	20,362	1,205	6,655	5,507	36,554	6,560
% BURNT	3	28	6	2	26	1	1	7	1	<1	14	1	12	1	4	3	22	4
TOTAL AREA OF NQ/POP HABITAT BURNT	477	13,717	5,490	105	21,888	187	211	2,009	203	1	8,460	402	15,871	28	13,38	3,034	15,710	4,851
% BURNT	1	21	8	<1	33	<1	<1	3	<1	<1	13	1	24	<1	2	5	24	7

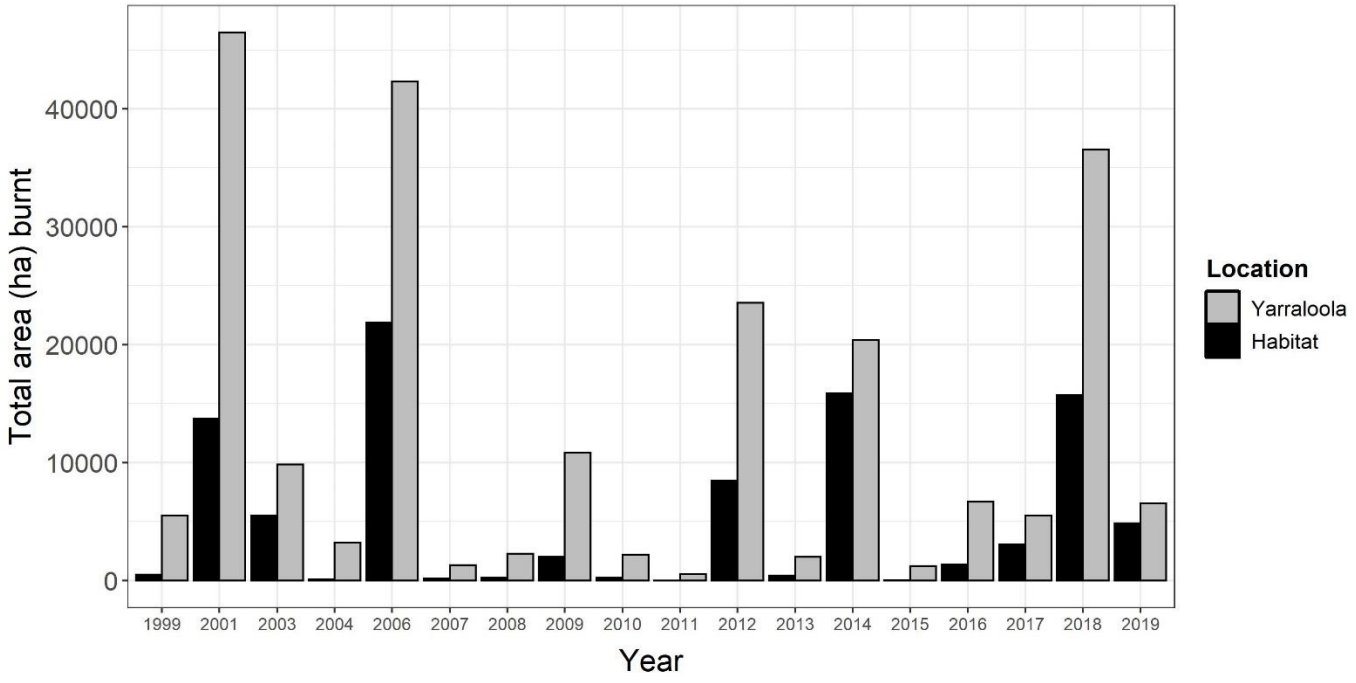

Figure 4 Total area (ha) burnt per year across Yarraloola LMA and NQ & POP habitat.

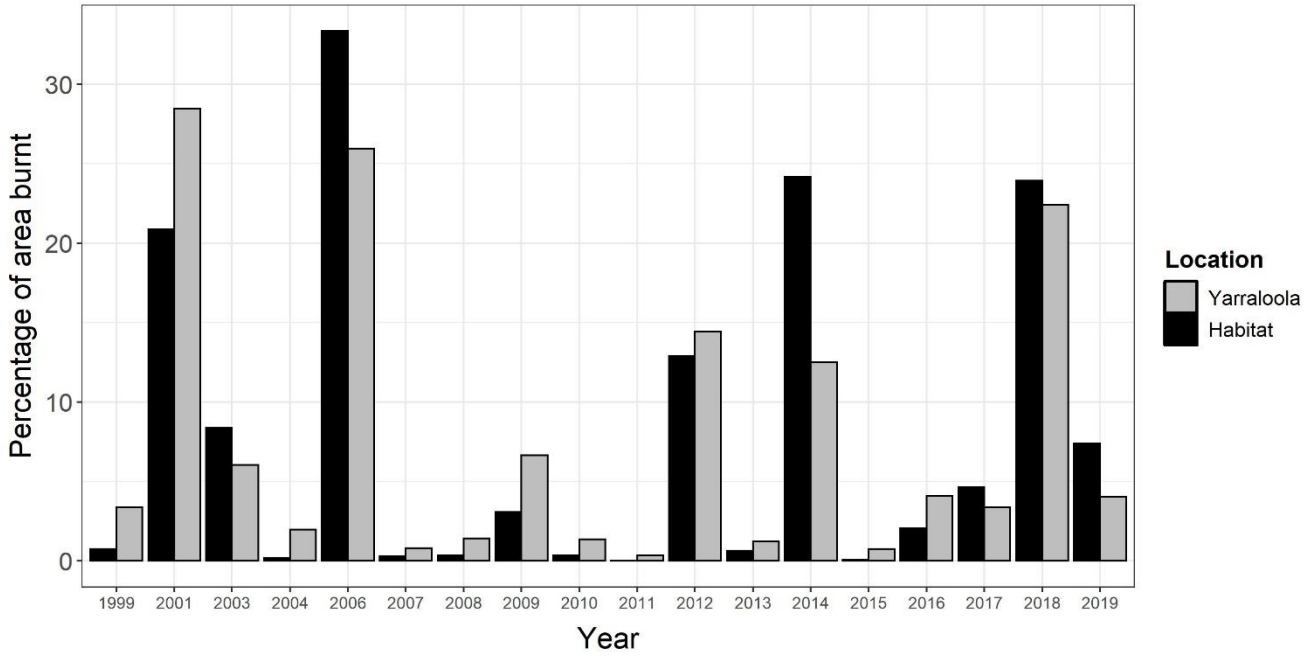

Figure 5 Total percentage burnt per year across Yarraloola LMA and NQ & POP habitat range.

3.1.2 Land systems

Table 7 displays the total area of land mapped as burnt across the different land system units. The percentages based on these area figures are displayed in Table 8. Graphs of the area statements are displayed in Figure 6 and percentages of those figures are displayed in Figure 7. Alternative graphs for displaying the metrics for the land systems across Yarraloola LMA are displayed in Figure 8 and Figure 9. These display the same data but give an alternative visual representation.

Table 7 Total area in hectares of area burnt over Yarraloola LMA within the land systems for each year of available fire mapping.

YEAR	1999	2001	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NNT	565	9,481	441	309	6,253	0	65	3,111	0	2	5,033	75	19	53	706	2,585	7,237	93
SRK	1,429	2,274	477	0	2,643	141	307	0	228	0	1,360	0	1,472	233	943	307	2,221	10
CPN	28	3,696	87	936	2,314	338	0	205	203	0	2,657	245	27	4	609	236	1,780	77
RIV	147	1,056	588	365	245	0	3	0	0	0	378	0	437	0	51	96	1,012	350
ROB	601	4,954	946	7	1,101	85	167	0	0	0	2,778	186	729	0	291	53	1,252	1,040
BGD	710	3,300	1,596	0	6,432	0	56	891	85	0	2,620	0	1,526	38	508	767	5,441	428
URY	715	3,183	643	0	4,780	815	22	67	1,672	0	2,273	0	528	657	1,424	29	2,299	437
STT	57	12,550	932	753	504	0	1,637	4,711	0	519	2,748	1,084	363	196	2,111	0	5,846	225
NEW	117	3,425	3,724	38	15,102	0	93	214	0	0	2,628	378	12,455	0	0	1,421	8,263	3,707
ROC	0	64	322	0	1,126	0	0	113	0	0	0	0	1,938	0	0	0	0	101
CAN	65	780	10	58	0	0	0	267	0	0	218	0	163	0	9	0	141	0
KUM	0	43	13	0	44	0	0	27	0	0	0	18	285	0	0	0	172	0
MAL	715	486	0	0	828	0	0	0	0	0	61	0	419	0	0	8	560	0
MCK	0	0	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93
PED	339	1,177	1	716	959	0	0	1,070	0	0	777	0	0	24	3	4	330	0

Table 8 Total percentage of area burnt over Yarraloola LMA within the land systems for each year of available fire mapping.

YEAR	1999	2001	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NNT	2	40	2	1	26	0	0	13	0	0	21	<1	<1	<1	3	11	31	<1
SRK	13	20	4	0	23	1	3	0	2	0	12	0	13	2	8	3	20	<1
CPN	<1	33	1	8	21	3	0	2	2	0	24	2	<1	0	5	2	16	1
RIV	2	16	9	6	4	0	<1	0	0	0	6	0	7	0	1	1	16	5
ROB	5	38	7	<1	8	1	1	0	0	0	21	1	6	0	2	<1	10	8
BGD	4	19	9	0	37	0	0	5	0	0	15	0	9	0	3	4	31	2
URY	6	25	5	0	38	6	0	1	13	0	18	0	4	5	11	<1	18	3
STT	<1	52	4	3	2	0	7	20	0	2	11	5	2	1	9	0	24	1
NEW	<1	11	12	<1	47	0	0	1	0	0	8	1	39	0	0	4	26	11
ROC	0	3	14	0	49	0	0	5	0	0	0	0	84	0	0	0	0	4
CAN	4	42	1	3	0	0	0	14	0	0	12	0	9	0	1	0	8	0
KUM	0	7	2	0	7	0	0	4	0	0	0	3	43	0	0	0	26	0
MAL	41	28	0	0	47	0	0	0	0	0	3	0	24	0	0	<1	32	0
MCK	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54
PED	8	27	0	17	22	0	0	25	0	0	18	0	0	1	<1	<1	8	0

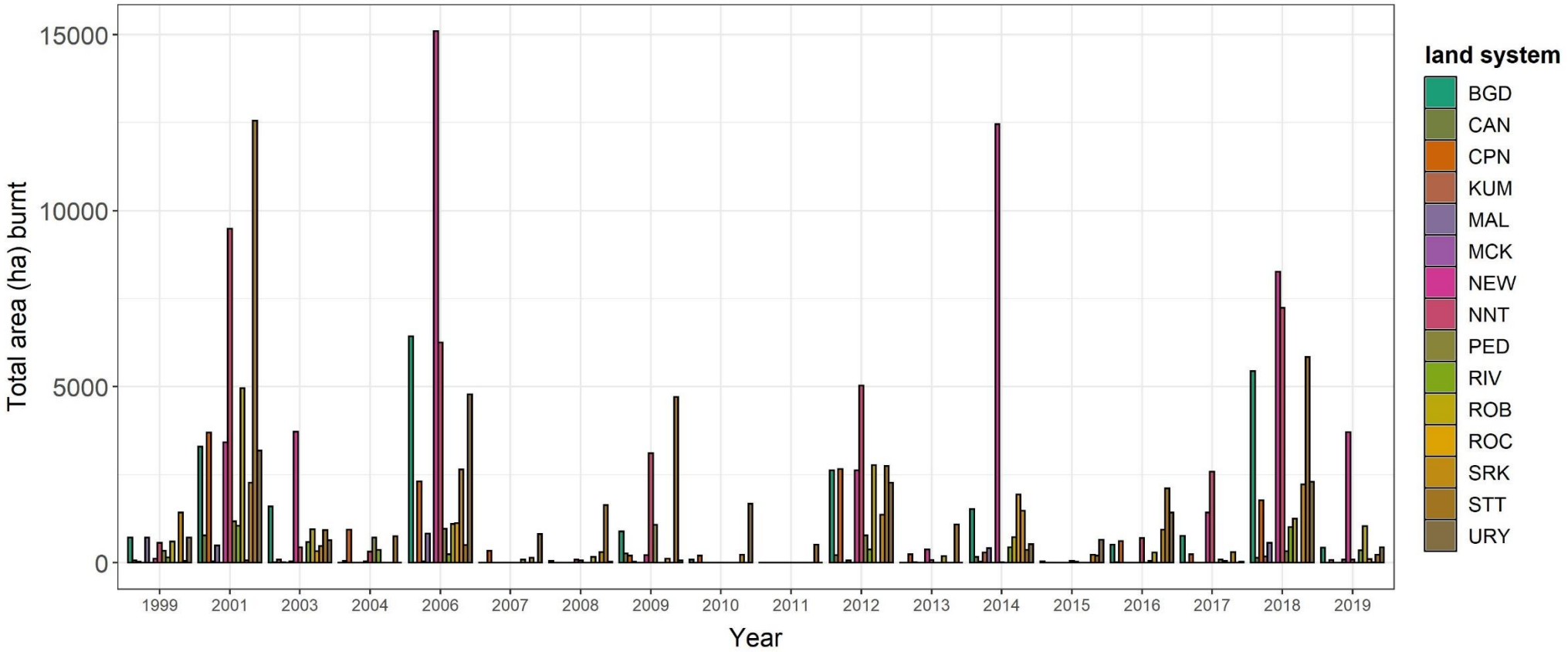

Figure 6 Total area (ha) burnt per year across Yarraloola LMA land systems for each year of available fire mapping.

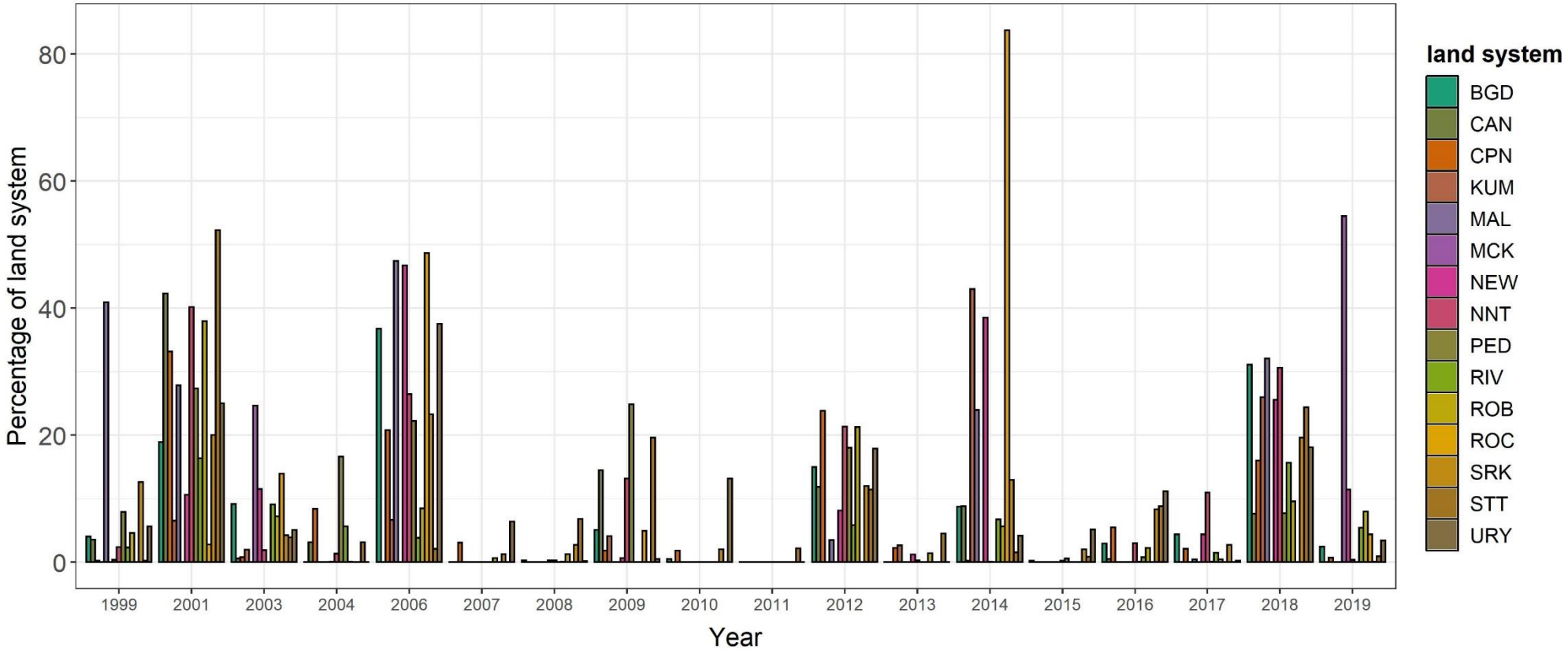

Figure 7 Total percentage burnt per year across Yarraloola LMA land systems for each year of available fire mapping.

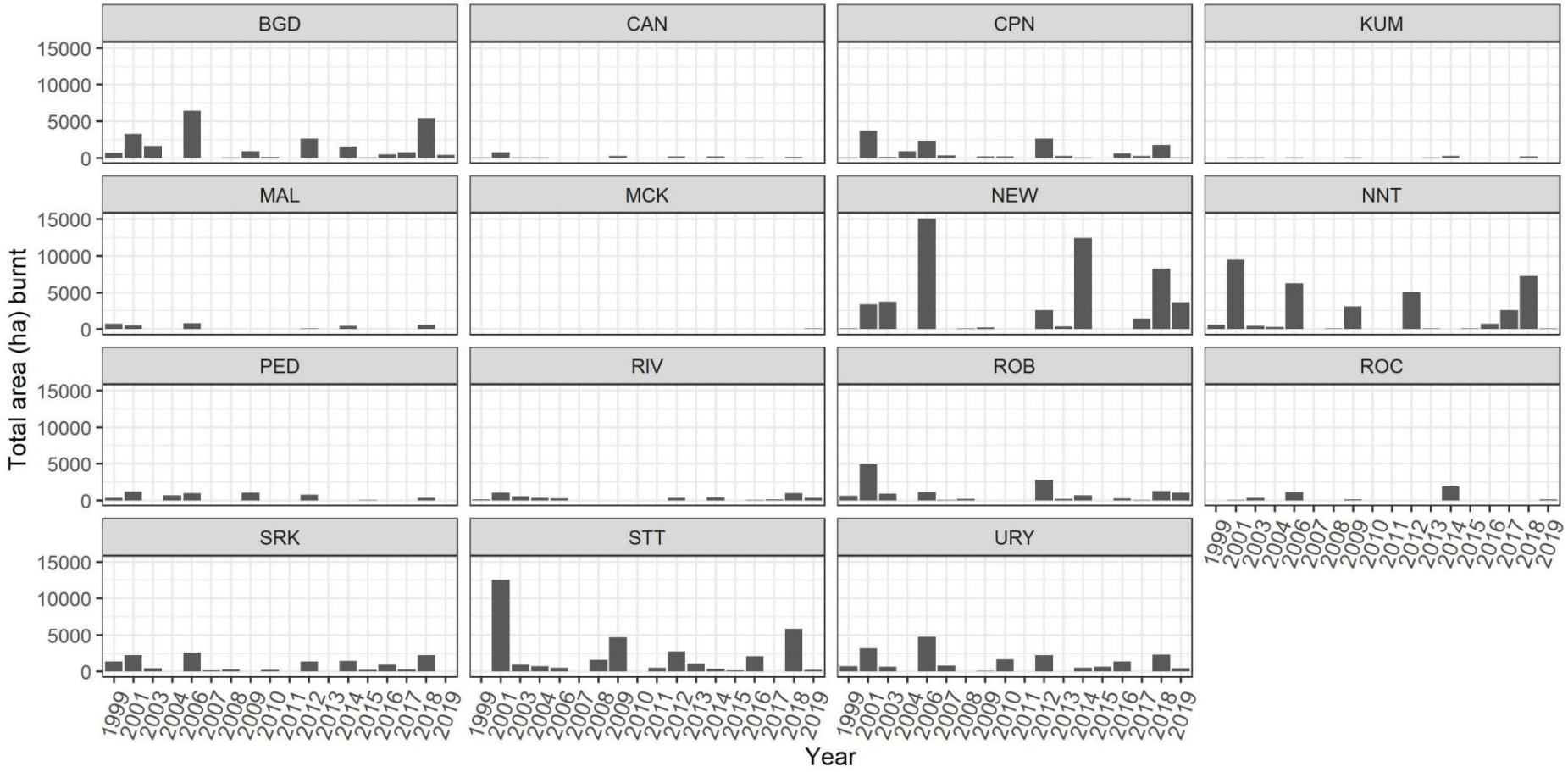

Figure 8 Alternative graph for total area (ha) burnt per year across Yarraloola LMA land systems for each year of available fire mapping.

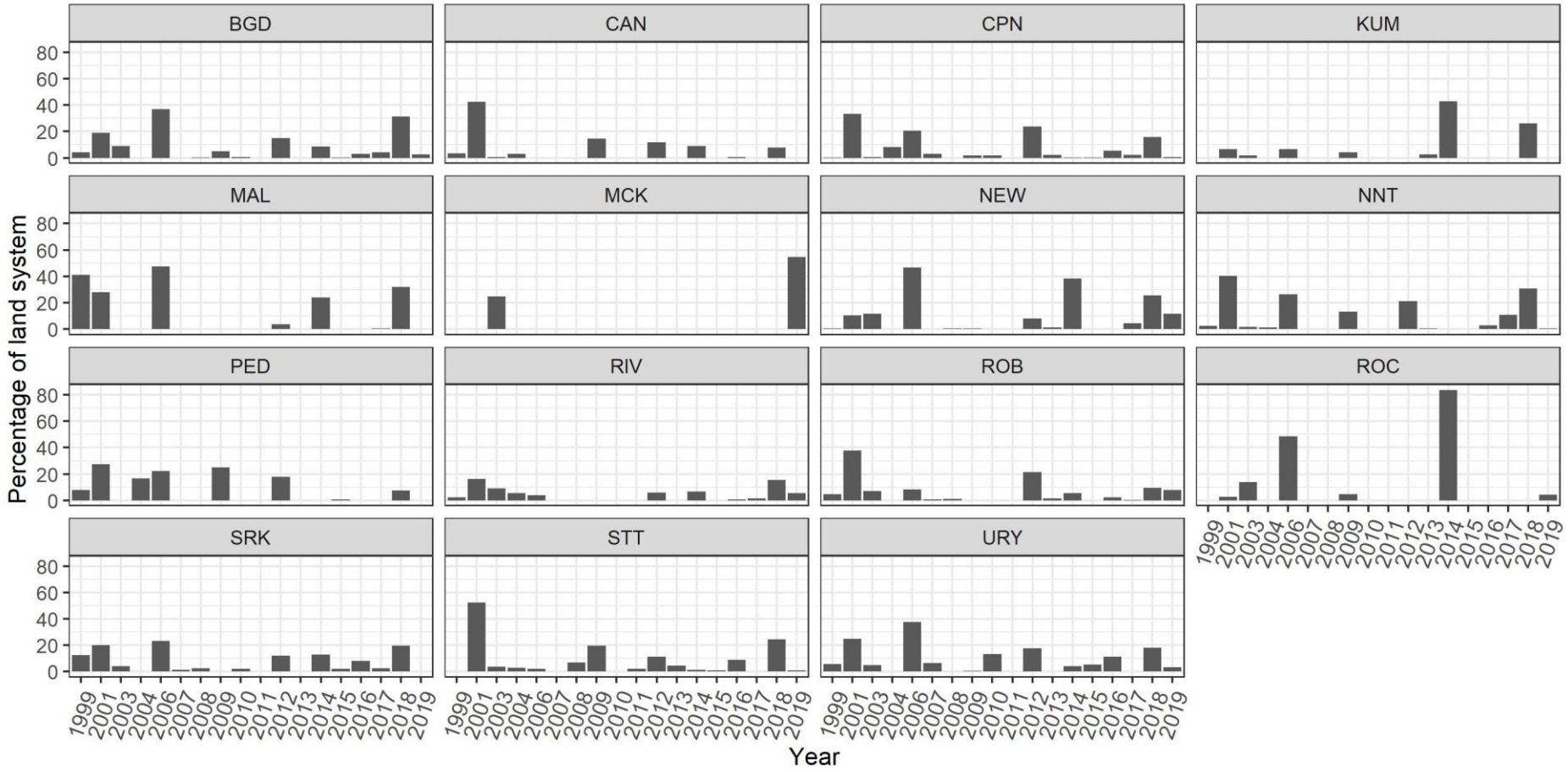

Figure 9 Alternative graph for total percentage burnt per year across Yarraloola LMA land systems for each year of available fire mapping.

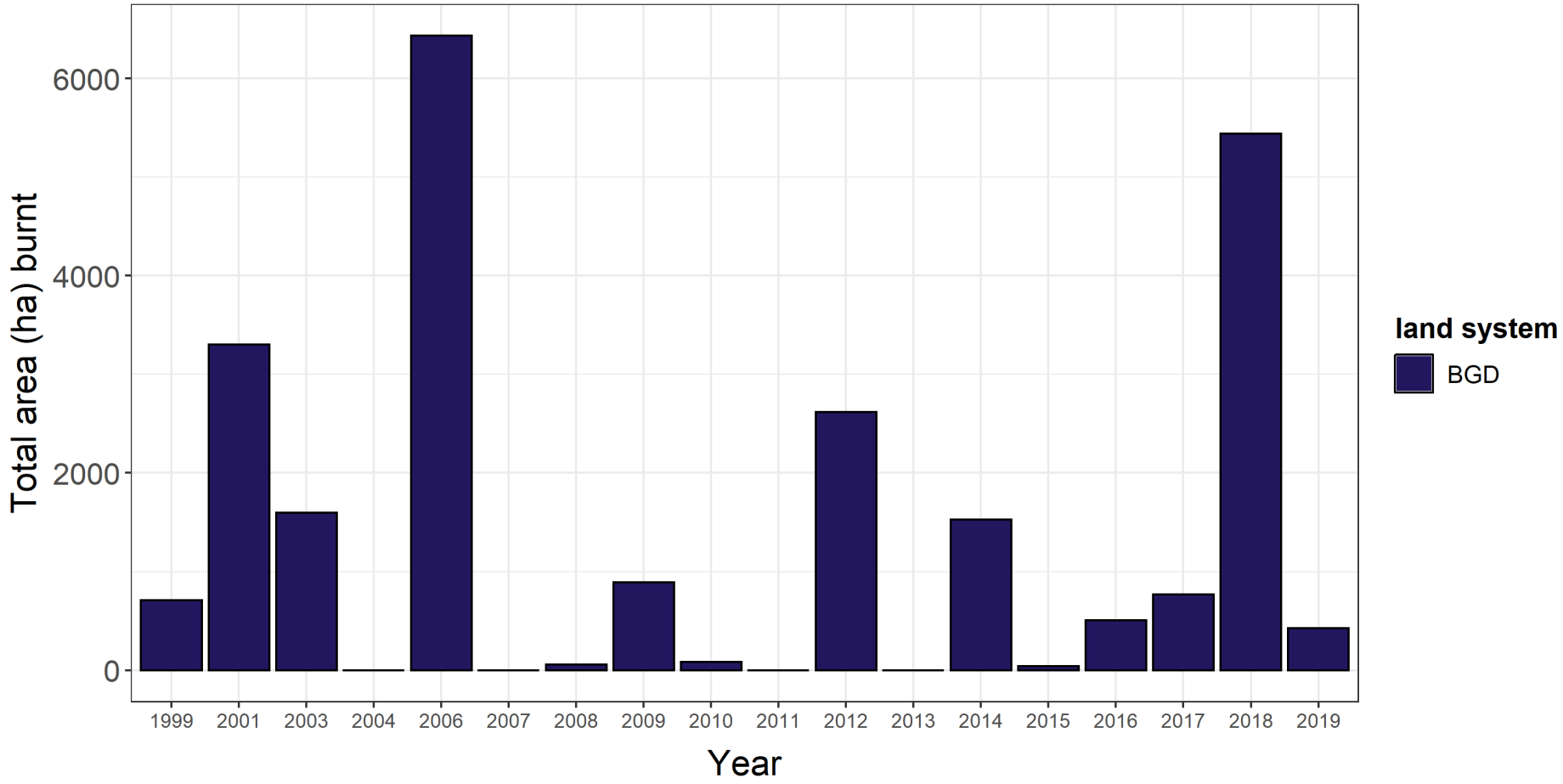

Figure 10 Total area (ha) burnt per year across the Boolgeeda land system for each year of available fire mapping.

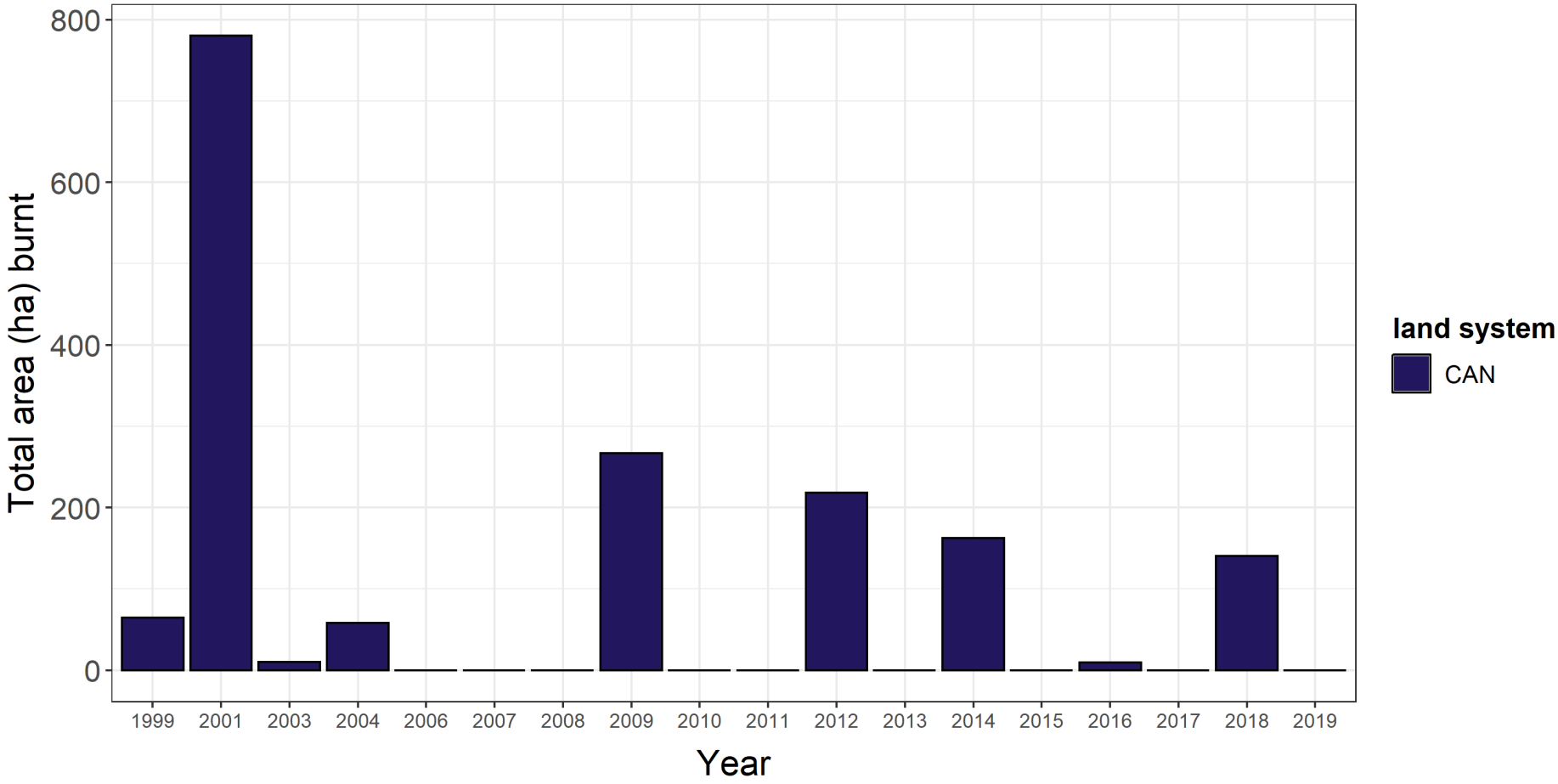

Figure 11 Total area (ha) burnt per year across the Cane land system for each year of available fire mapping.

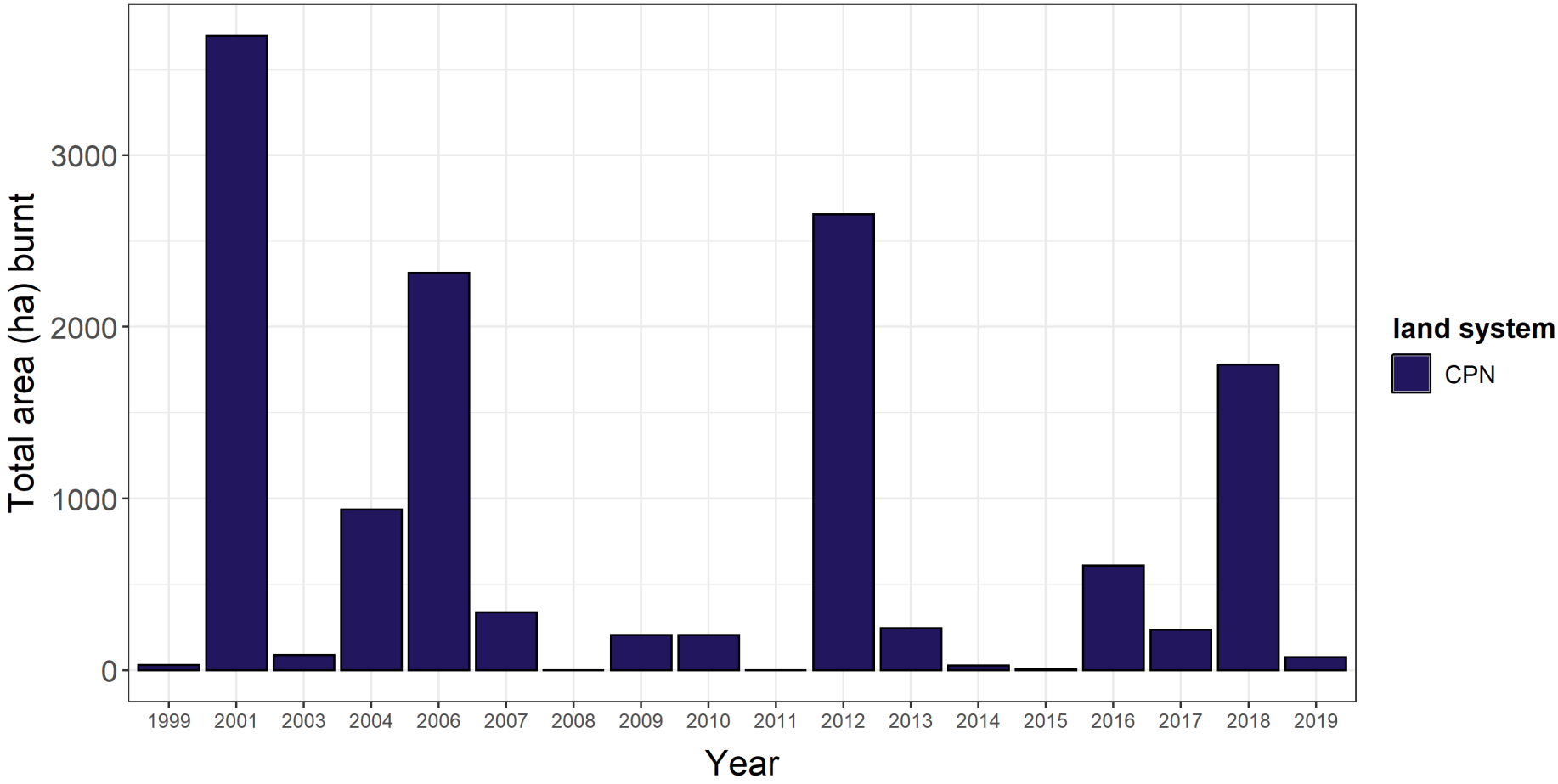

Figure 12 Total area (ha) burnt per year across the Capricorn land system for each year of available fire mapping.

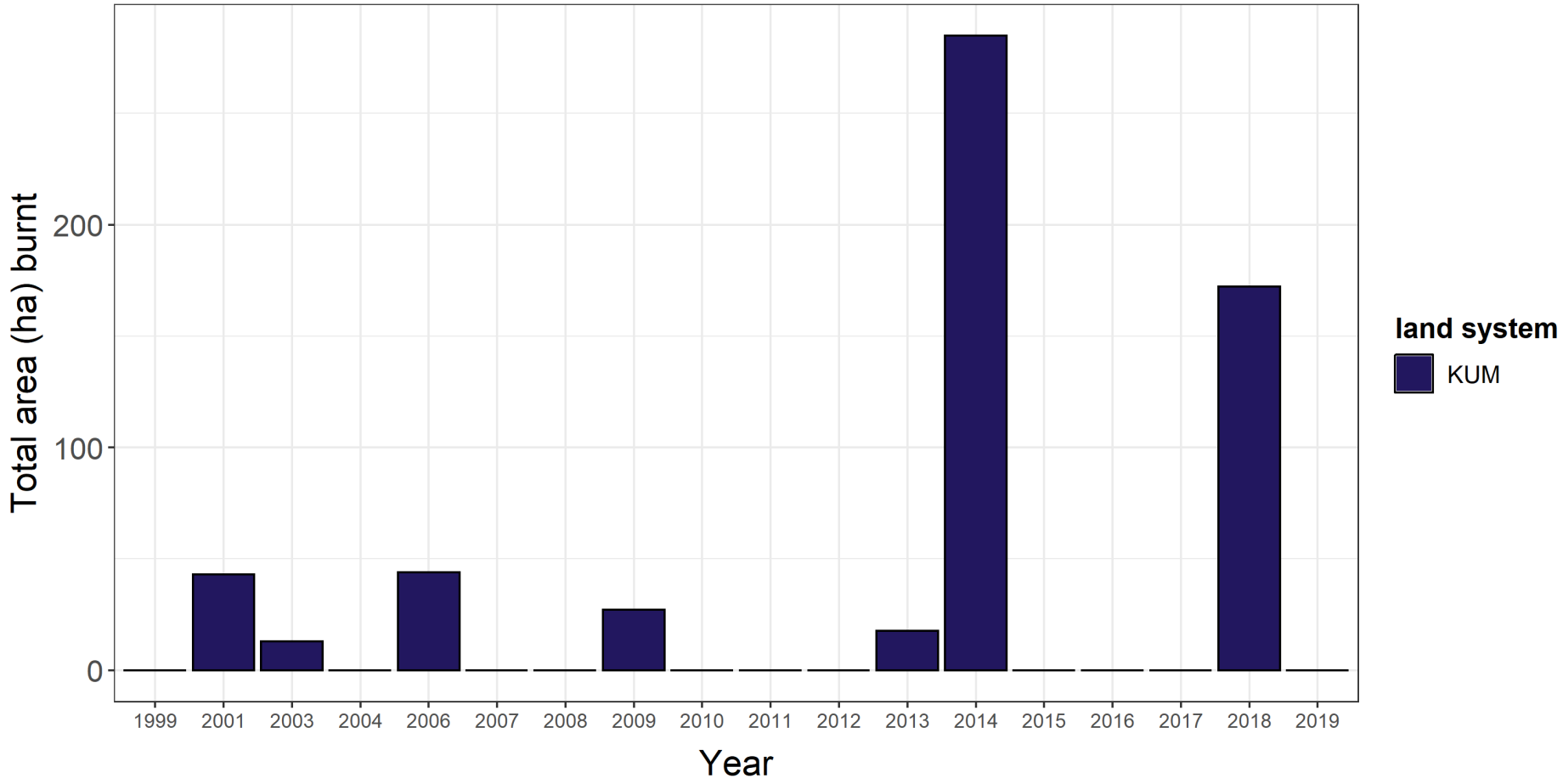

Figure 13 Total area (ha) burnt per year across the Kumina land system for each year of available fire mapping.

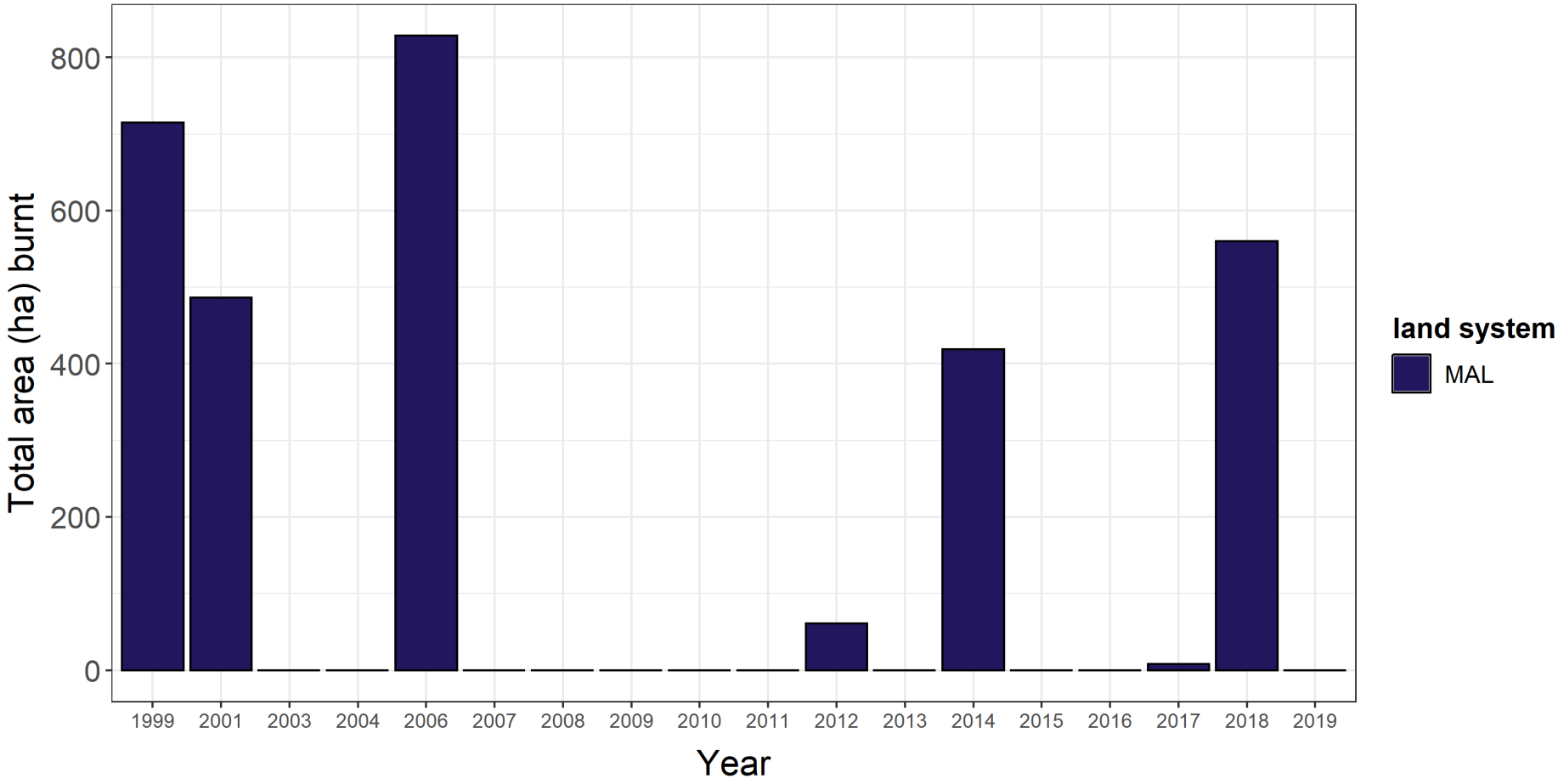

Figure 14 Total area (ha) burnt per year across the Mallina land system for each year of available fire mapping.

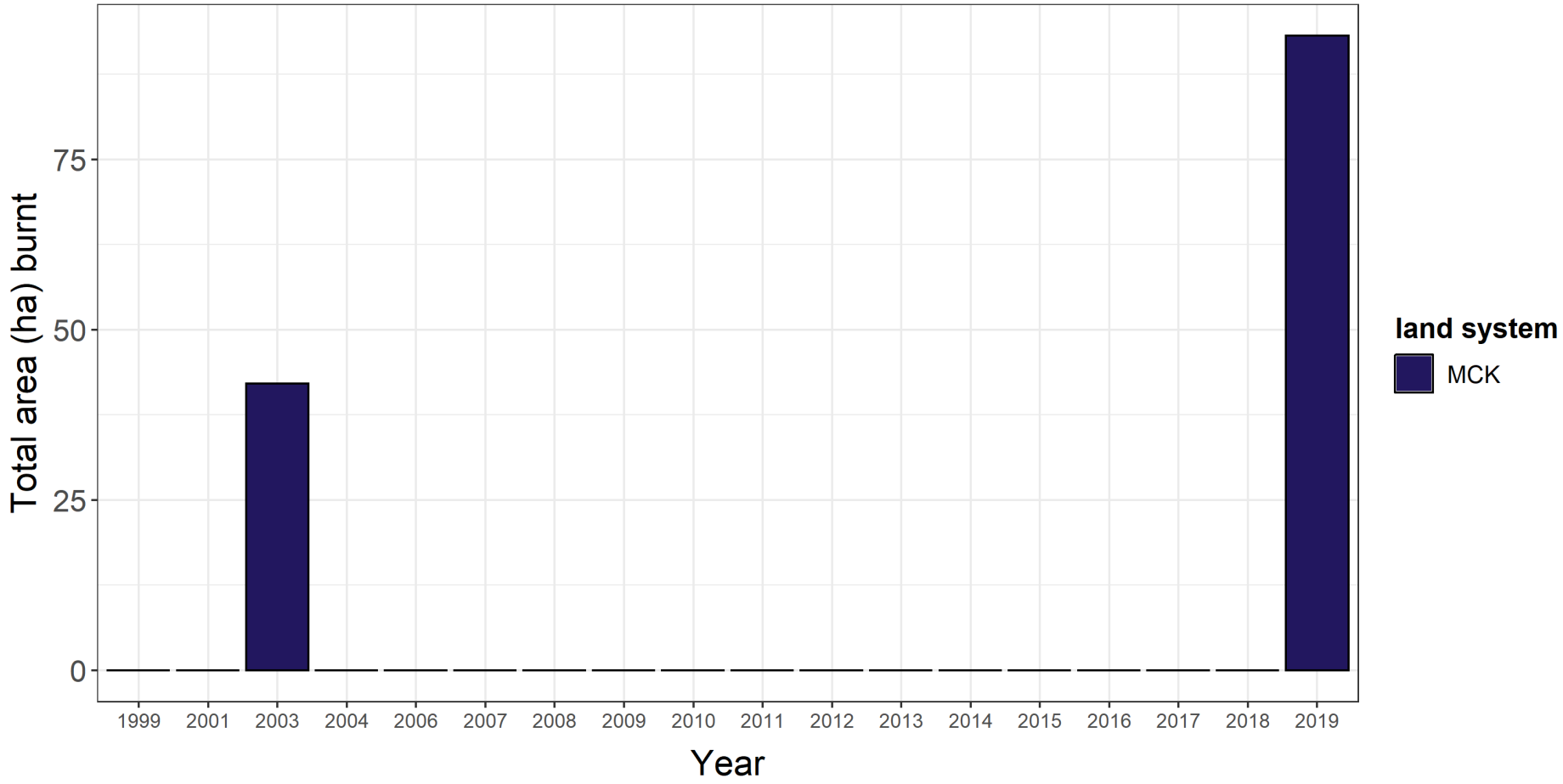

Figure 15 Total area (ha) burnt per year across the McKay land system for each year of available fire mapping.

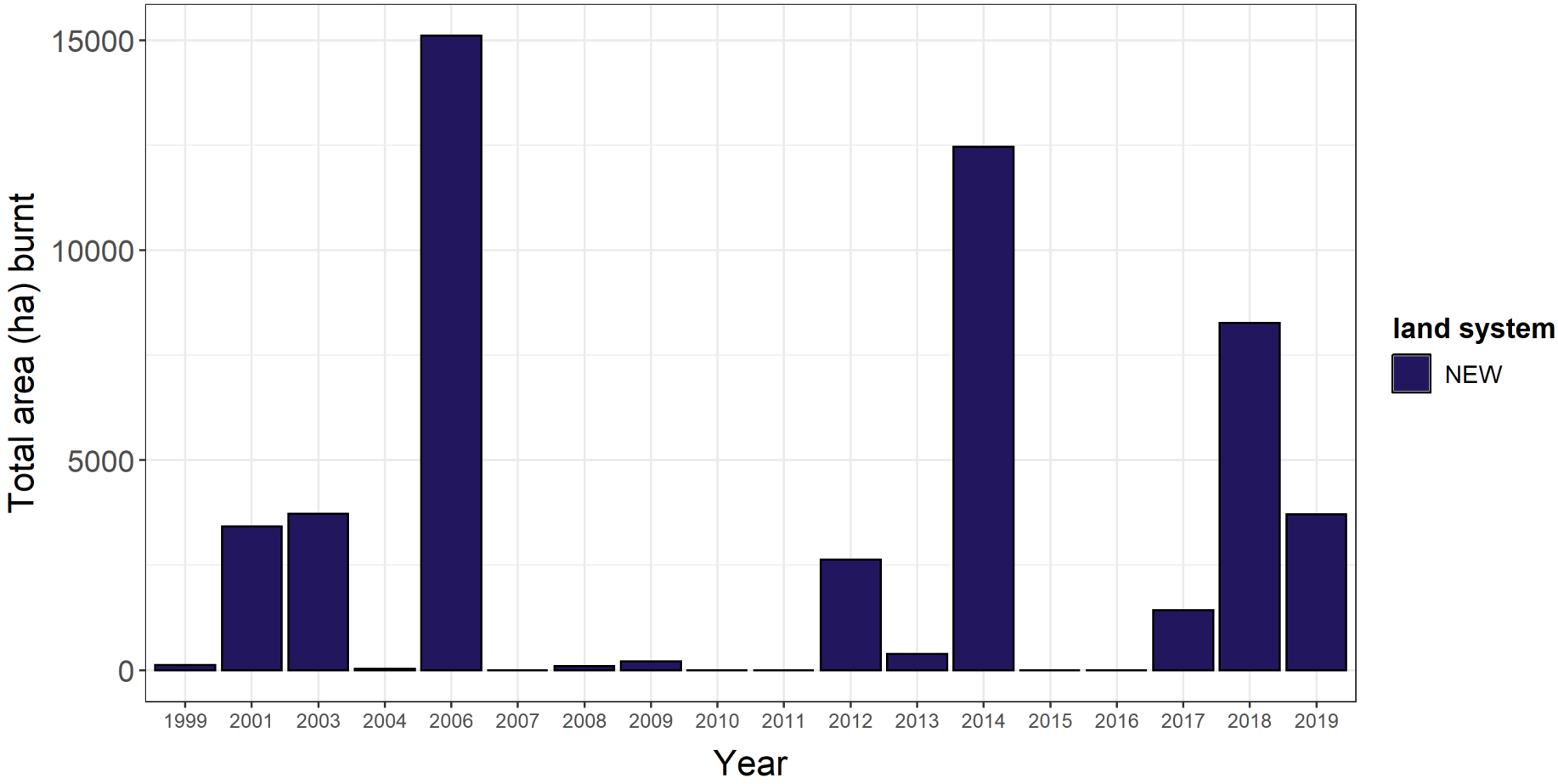

Figure 16 Total area (ha) burnt per year across the Newman land system for each year of available fire mapping.

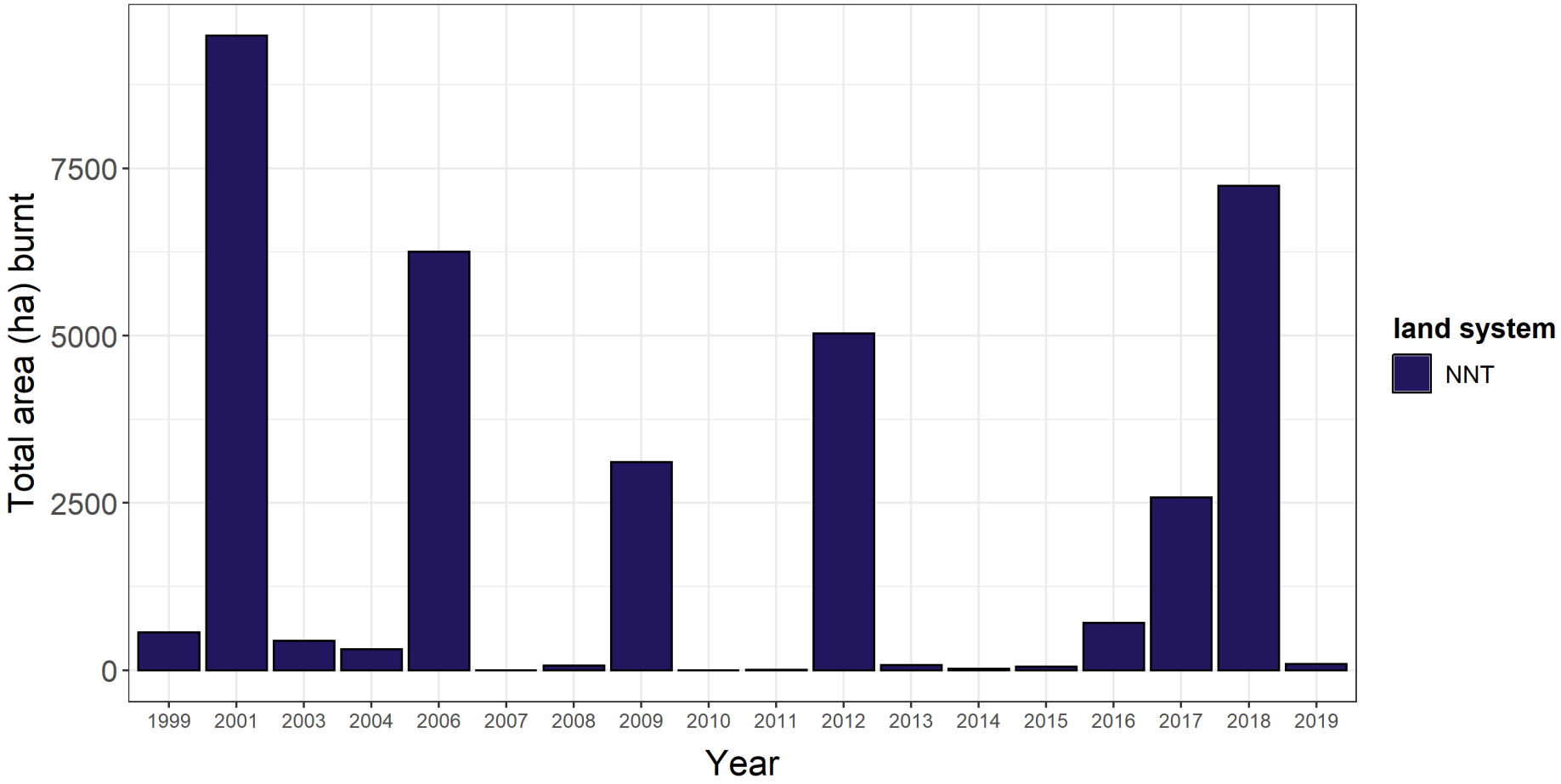

Figure 17 Total area (ha) burnt per year across the Nanutarra land system for each year of available fire mapping.

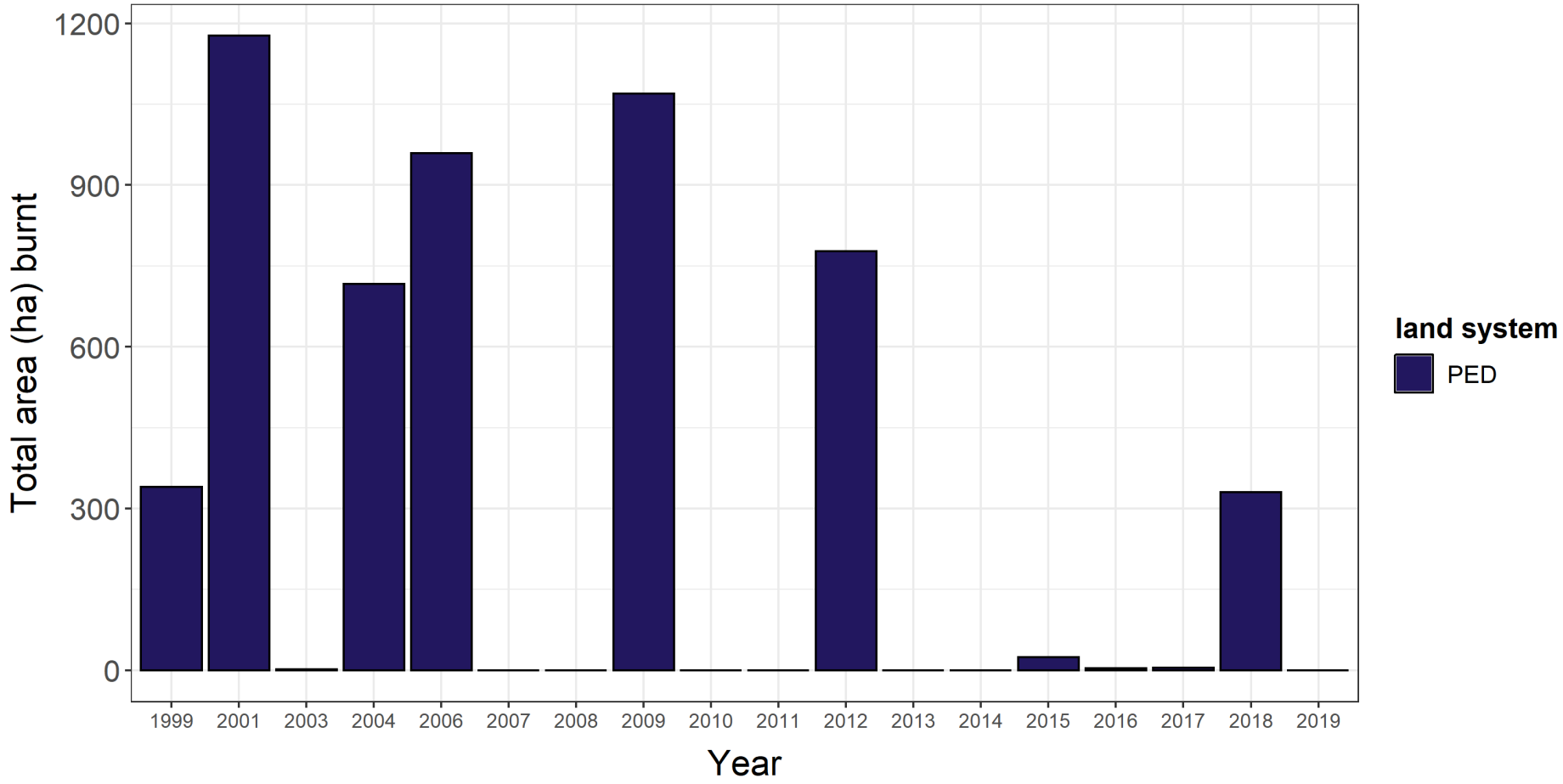

Figure 18 Total area (ha) burnt per year across the Peedamulla land system for each year of available fire mapping.

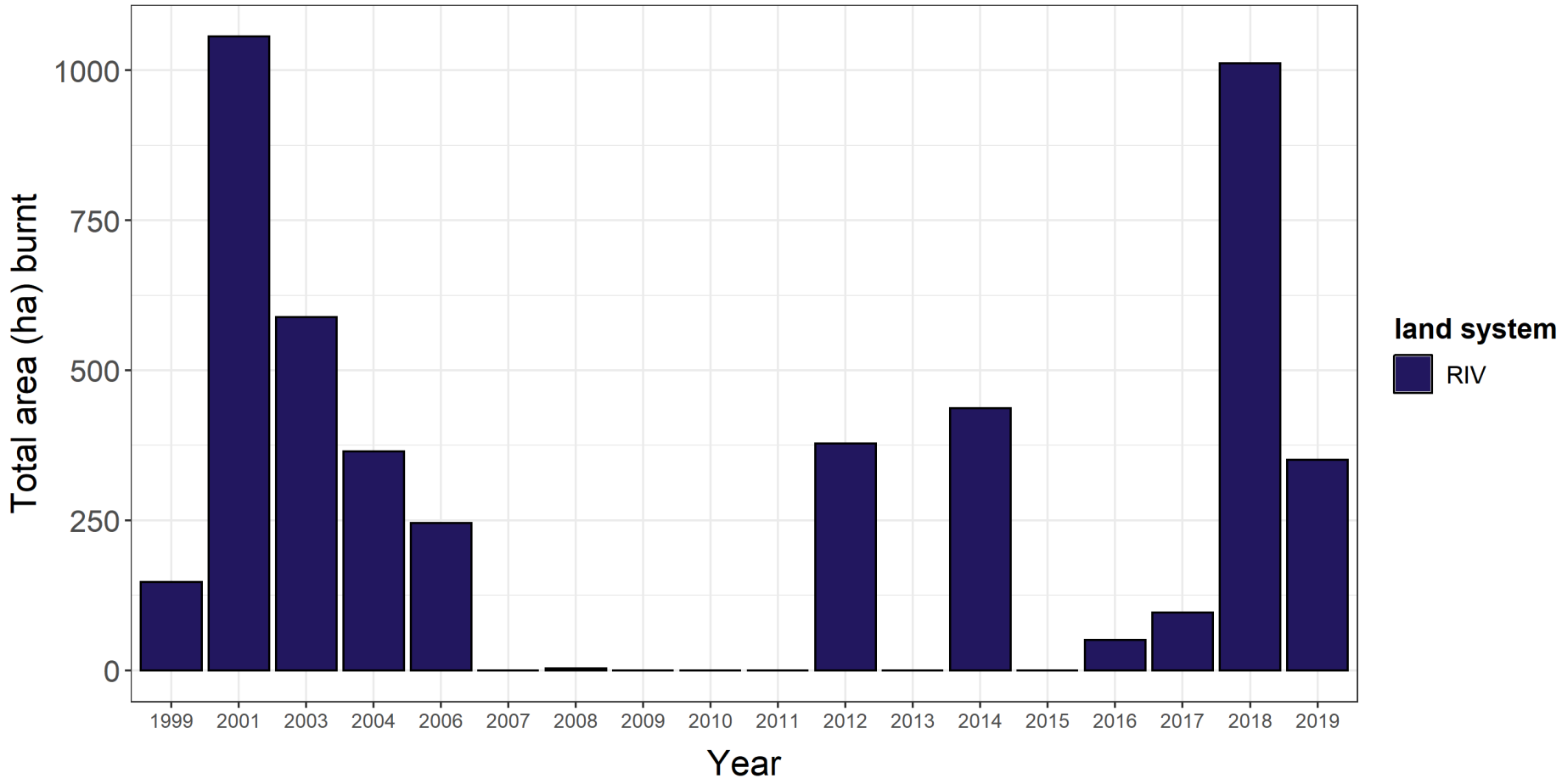

Figure 19 Total area (ha) burnt per year across the River land system for each year of available fire mapping.

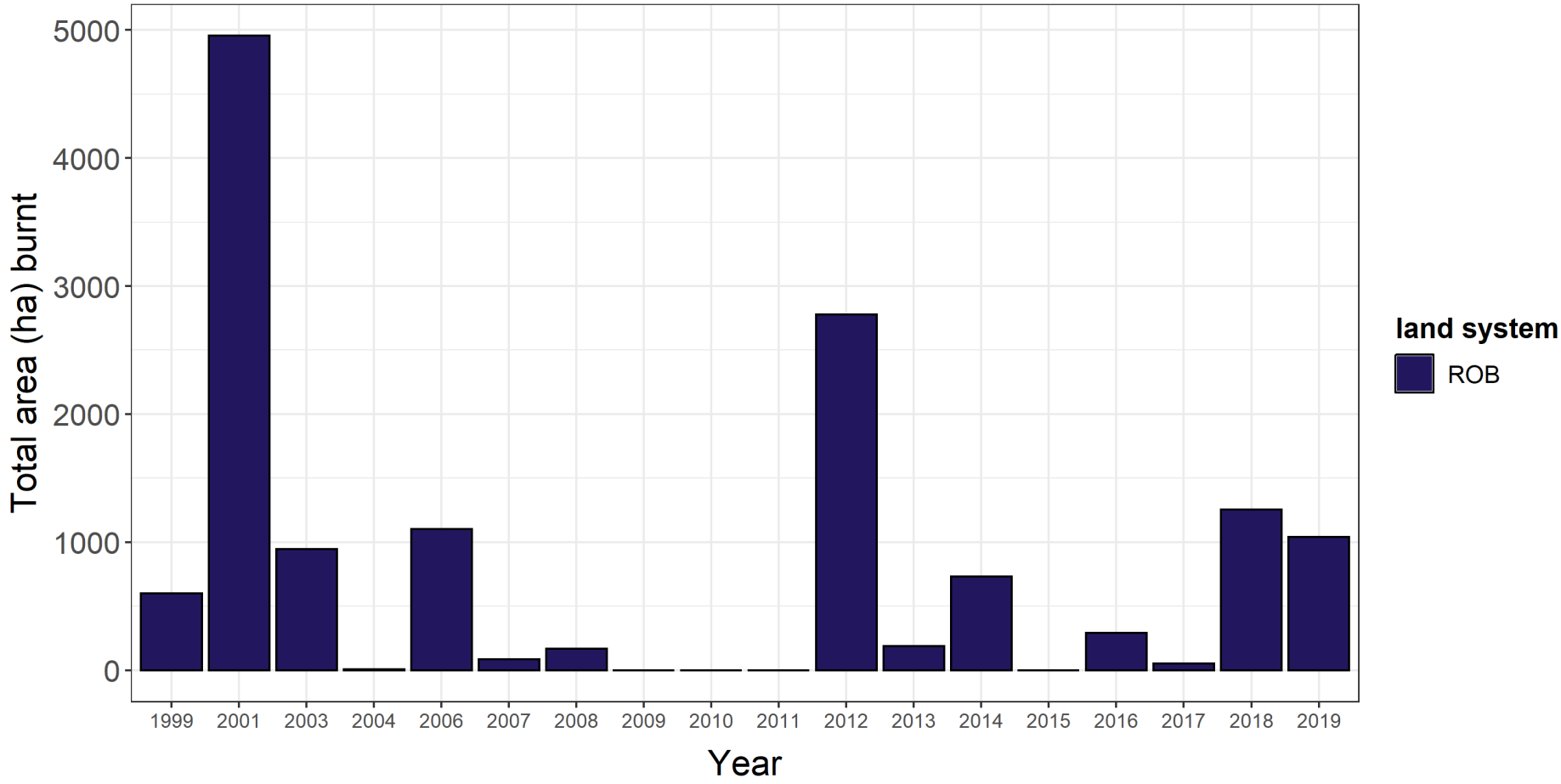

Figure 20 Total area (ha) burnt per year across the Robe land system for each year of available fire mapping.

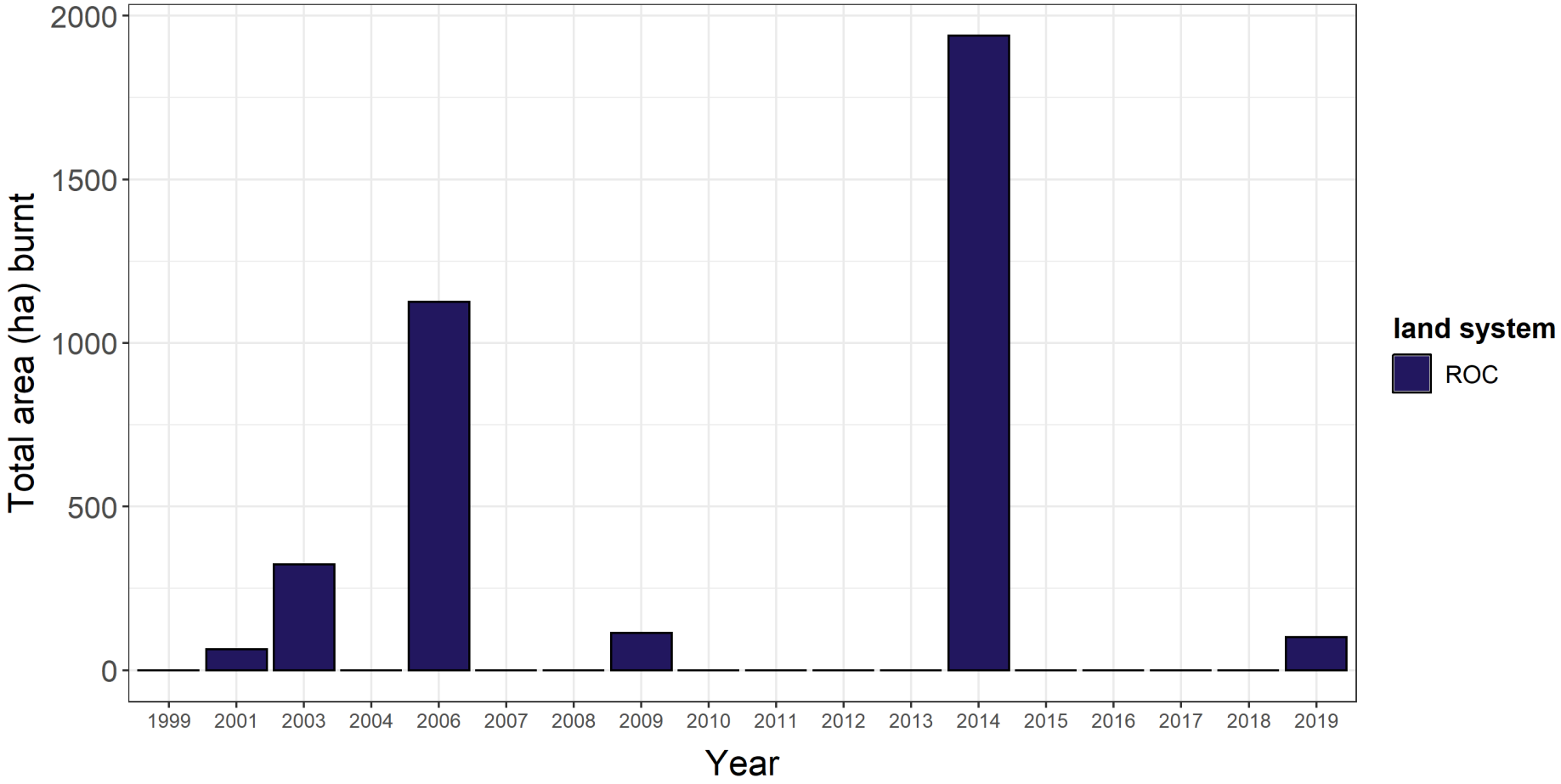

Figure 21 Total area (ha) burnt per year across the Rocklea land system for each year of available fire mapping.

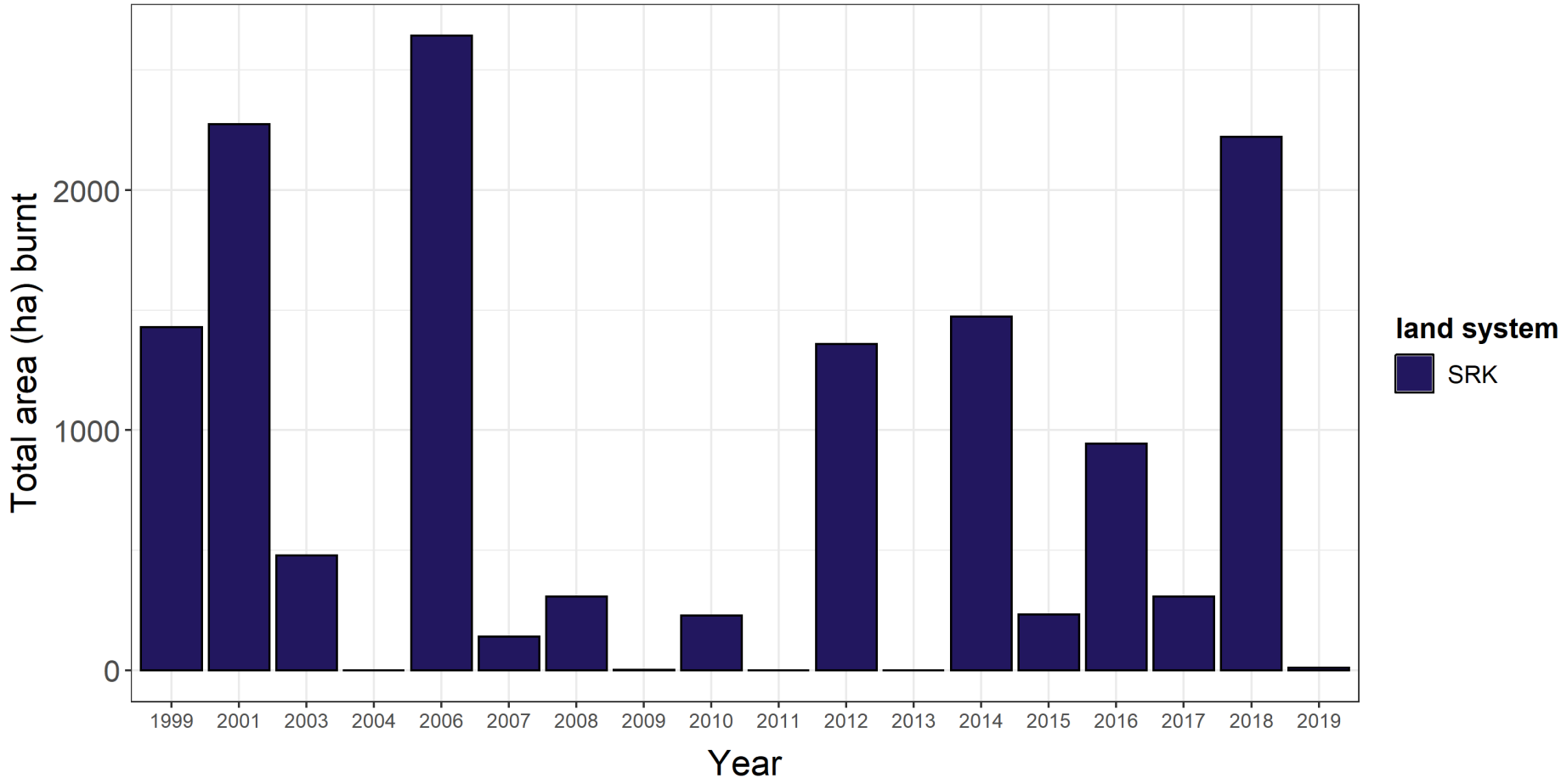

Figure 22 Total area (ha) burnt per year across the Sherlock land system for each year of available fire mapping.

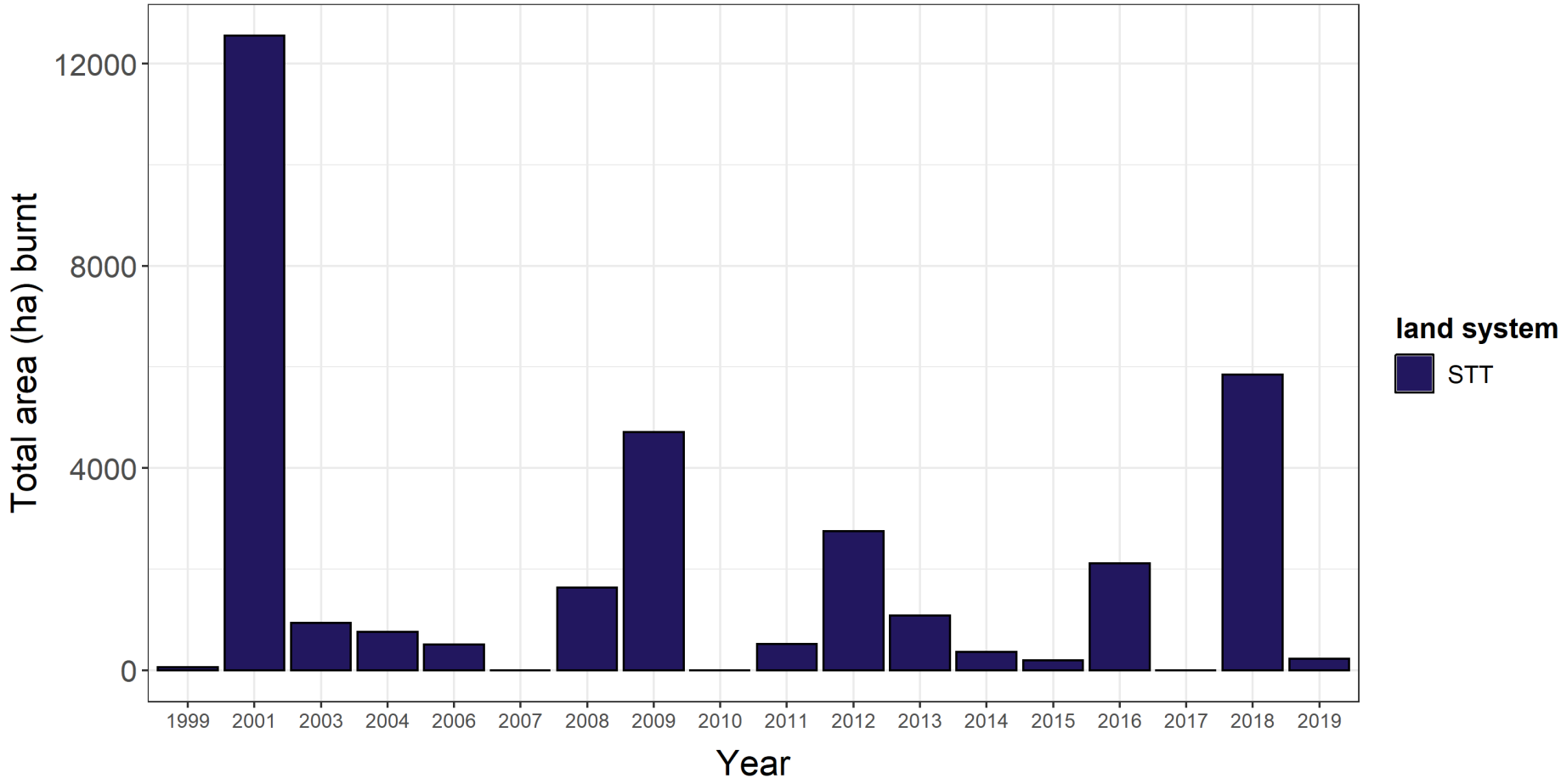

Figure 23 Total area (ha) burnt per year across the Stuart land system for each year of available fire mapping.

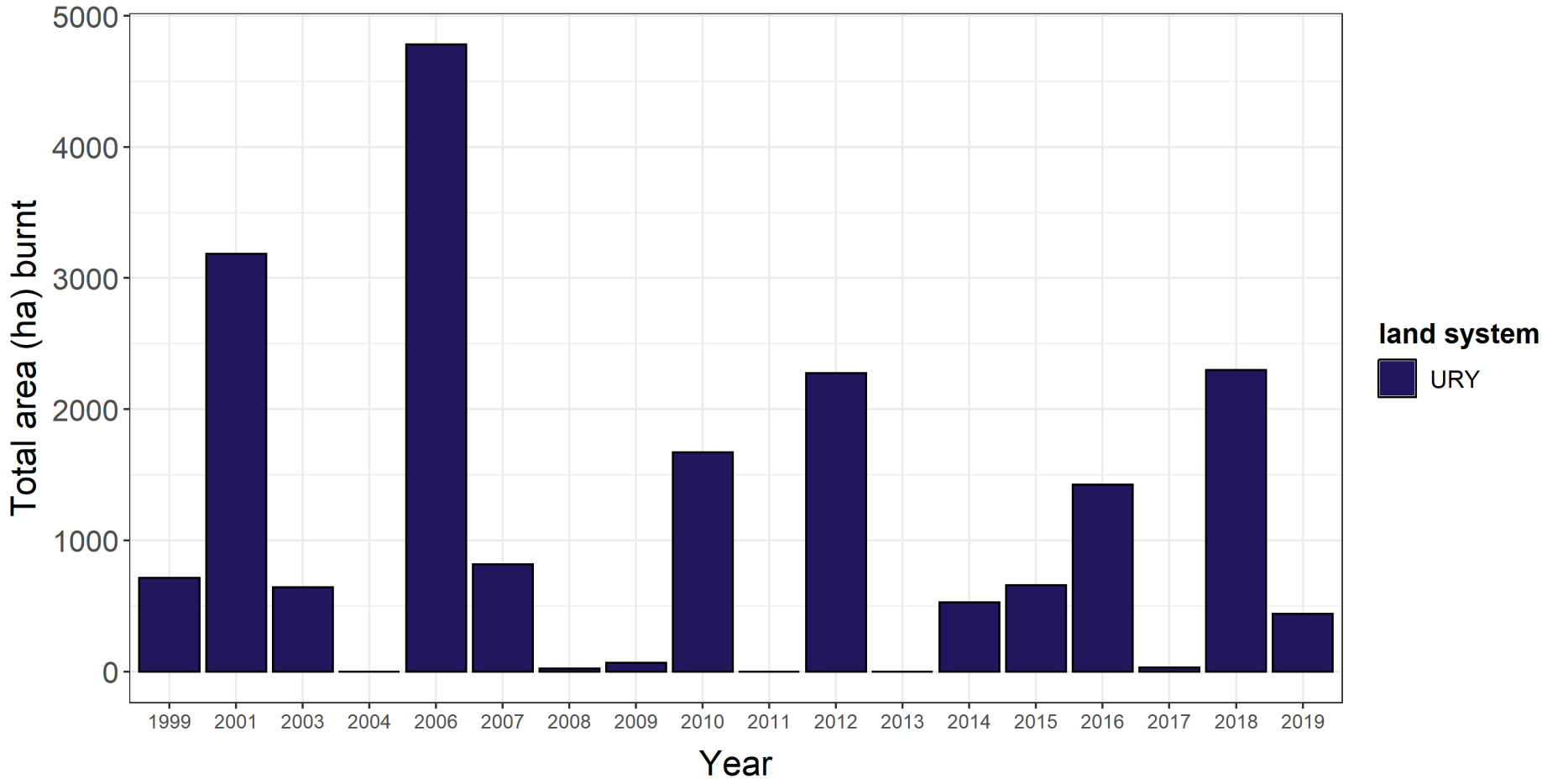

Figure 24 Total area (ha) burnt per year across the Urandy land system for each year of available fire mapping.

4 Data limitations

4.1 Spatial resolution

Landsat satellite imagery has a 30 m pixel resolution for the reflectance bands which are used for extracting fire scars. Small fires less than 30 m X 30 m and detailed edging around larger fires are not able to be extracted at this resolution. Due to the uncertainty around the smaller fires any isolated area of mapped ‘fire’ less than 1 hectare is deleted from the final dataset.

4.2 Fire date attribution

At this current time it is not possible to attribute the fire scar data with monthly date attribution for every month of the year. Fire scars are currently mapped using a difference image between two dates which are generally one year apart; occasionally they are mapped more frequently. Using this method we are only capable of showing the change in the vegetation between those two dates and as such can only determine that the fire occurred at some point in that year interval.

4.3 Size class distribution of fire scars

To calculate metrics based on the size class distribution of fire scars it must first be possible to attribute the fire scars with a more accurate date. The fire scars represent an annual change in vegetation cover over an area. For example; if a fire starts in March and burns 50 ha before extinguishing then another fire starts in June and burns another 50 hectares right up to the boundary of the March fire an annual snapshot of that area would show one larger fire of 100 ha rather than two smaller 50 ha fires a few months apart in age. Calculating metrics based on size class distribution using the current fire scar data could overestimate the percentage of larger fires.

4.4 Missing annual fire scar data

Historical fire scar data for years 2000, 2002 and 2005 is not available; therefore, comparisons of annual changes in fire scar area cannot be made for the period 1999 – 2006. Where there are greater than annual gaps the fire scars identified could have occurred at any time within the two-year period between image dates. This impacts the fire metric analysis in that statistics such as average burnt area per year cannot be calculated across the entire time period.

The table below indicates the imagery dates for previous years fire mapping.

Table 9 Historical fire mapping image sources and dates over Yarraloola pastoral lease

Source data	Image date	Mapping Year
NCAS	23/11/1999	1999
NCAS	16/02/2002	2001
NCAS	21/06/2004	2003
NCAS	16/02/2005	2004
NCAS	06/02/2007	2006
NCAS	04/10/2007	2007
NCAS	10/01/2009	2008
NCAS	14/02/2010	2009
USGS	23/12/2010	2010
USGS	12/02/2012	2011
USGS	02/03/2013	2012
USGS	25/02/2014	2013
USGS	16/03/2015	2014
USGS	29/12/2015	2015
USGS	31/12/2016	2016
USGS	18/12/2017	2017
USGS	06/01/2019	2018
USGS	24/12/2019	2019

4.5 Landsat 7 SLC-Off missing data strips

During the period November 2011 to April 2013 the only available Landsat imagery was from Landsat 7 ETM+ and this imagery had missing data lines (‘stripes’) which affects the detection and attribution of fires scars. This results in some fires having ‘stripes’ of missing mapping which then affects the calculation of areas, fuel age and fire frequency.

Landsat images affected by the Scan Line Corrector (SLC) failure are missing approximately 22% of data. Generally the most area lost is towards the edges of the scene with the middle of a scene unaffected. Figure 25 shows an example of the area of the Yarraloola LMA affected by the SLC failure in 2012. The white stripes in the image represent missing data.

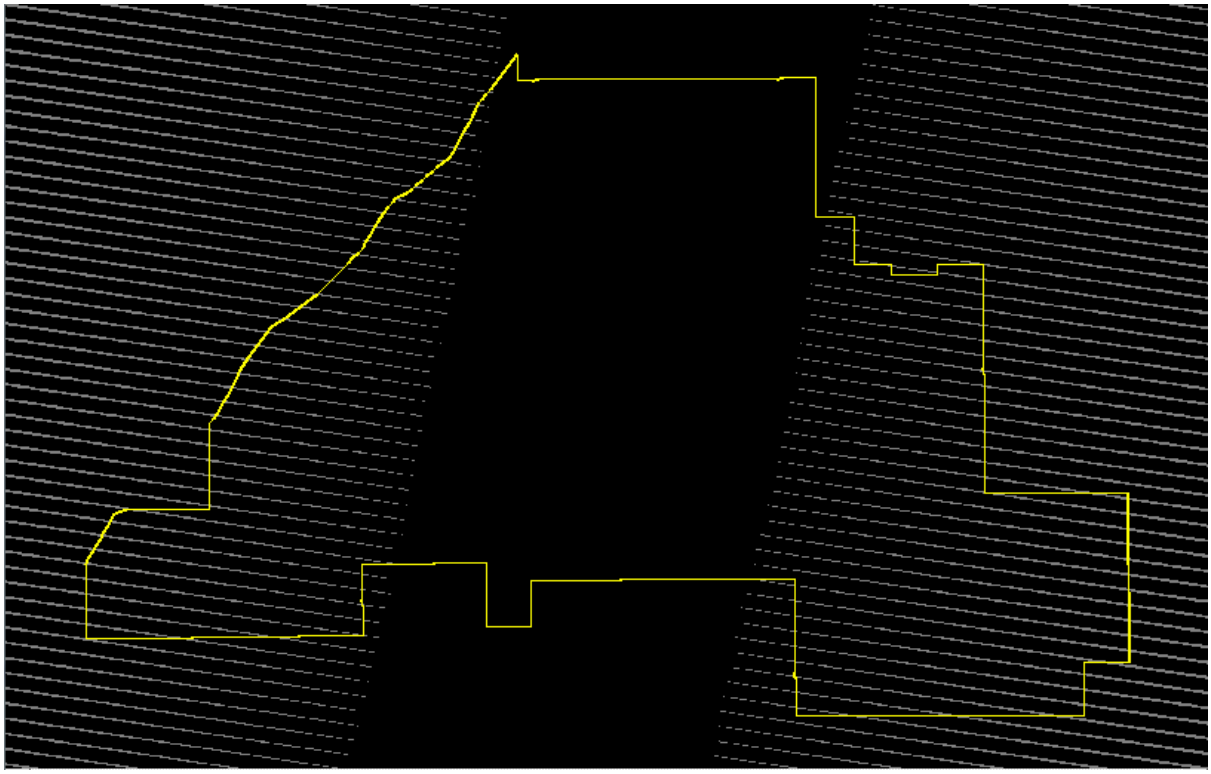

Figure 25 Location of missing data across the Yarraloola LMA for Landsat image date 02/03/2012.

Landsat 7 images affected by the SLC failure were used for the fire mapping in years 2012 and 2013. Within the Yarraloola LMA approximately 5.7% of the Landsat 7 image data was missing for the 2012 mapping and approximately 5.8% of the Landsat 7 image was missing for the 2013 mapping.

Table 10 Percentage of area within the Yarraloola LMA which is missing data for affected image dates.

Landsat 7 image date	Percentage of area no data
12/02/2012	5.7
02/03/2013	5.8

References

Chapman, J., Zdunic, K., (2016). Yarraloola annual desktop fire regime monitoring: 2015. Department of Parks and Wildlife, Kensington, WA.

Honeycutt, D., (2012). “Counts overlapping polygons”. ArcMap toolbox, http://www.arcgis.com/home/item.html?id=1dd4a6832b3d40b494dbf8521cc5134c

R Core Team, (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

van Vreeswyk, A. M., Leighton, K. A., Payne, A. L., and Hennig, P., (2004). An inventory and condition survey of the Pilbara region, Western Australia, Department of Agriculture and Food, Western Australia. Technical Bulletin 92, 424p.

Data delivery

Datum and projection: GDA 94 MGA50

Date delivered: 25/08/2020

Contact: Katherine Zdunic/Jane Chapman, Remote Sensing Science, Department of Biodiversity, Conservation and Attractions

17 Dick Perry Avenue, Kensington. Katherine.Zdunic@DBCA.wa.gov.au, Jane.Chapman@dbca.wa.gov.au

Dataset Delivered	**Format**	**Description**
Yarraloola_Fire_1998_2019_10km_buff	ESRI shapefile	Fire scar mapping for Yarraloola LMA and surrounding area within a 10 km buffer for the time period 1999 – 2019 for all available years
Yarraloola_2019_Fire_stats_report	PDF	This report document
Yarraloola_graphs	JPEG	The graphs contained in the report as JPEGs derived from the raw data
yarraloola_total_area_burnt_years_stats_2019	Excel csv	Raw data

Appendix 2: Annual desktop fire regime monitoring Red Hill

GOVERNMENT OF WESTERN AUSTRALIA

Department of **Biodiversity, Conservation and Attractions**

Red Hill annual desktop fire regime monitoring: 2019

Version: 2

Approved by: Russell Palmer

Last Updated: 25/8/2020

Custodian: Department of Biodiversity, Conservation and Attractions

Review date:

Version number	Date approved DD/MM/YYYY	Approved by	Brief Description
1	5/8/2020	Russell Palmer	No edits required
1	11/08/2020	Tessa Elvey, Jason Rossendell	Minor edits and formatting
2	25/08/2020	Tessa Elvey, Jason Rossendell	Formatting, additional land systems graphs added, minor edits

Red Hill annual desktop fire regime monitoring: 2019

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[1]Research Officer (Remote Sensing)

[2]Senior Research Officer (Remote Sensing)

August 2020

GOVERNMENT OF WESTERN AUSTRALIA

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July 2020

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Department Biodiversity, Conservation and Attractions, 2020, *Red Hill annual desktop fire regime monitoring: 2019*, Department of Biodiversity, Conservation and Attractions, Perth.

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This document is available in alternative formats on request.

Please note: urls in this document which conclude a sentence are followed by a full point. If copying the url please do not include the full point.

Contents

Figures

Tables

Summary

This report addresses the tasks outlined in the document “Scope of Works - DPaW TSOP Fire Regime Monitoring 2019” and includes fire metrics over the Red Hill Land Management Area (LMA) for the time period 1999 – 2019.

The fire metrics contained in this report are listed in Table 1.

Table 1 Fire metrics covered in the report for the period 1999 – 2019

Metric	**Status**
Total area (ha) and proportion burned each year ▪ across entire study area ▪ within land system units ▪ within mapped Northern Quoll (NQ) & Pilbara Olive Python (POP) habitat	Achieved

The project area known as the Red Hill Land Management Area (LMA) is indicated in blue on Figure 1, and indicates the area subject to analysis, the LMA covers 187,708 hectares. In order to understand fires that occur close to or overlap this boundary a 10km buffer area for the provided vector mapping of the fires is delivered for map production use only. The composite land system mapping and fauna habitat areas used in the analysis have been supplied by Rio Tinto (Final Red Hill NQ POP habitat combined_region.shp and 2016_Red Hill_LandSystems_exported.shp).

For information on image processing, fire mapping and satellite imagery please see previous monitoring reports by Chapman and Zdunic (2016). Methodology describing the creation of the fire scar dataset will not be included in this update.

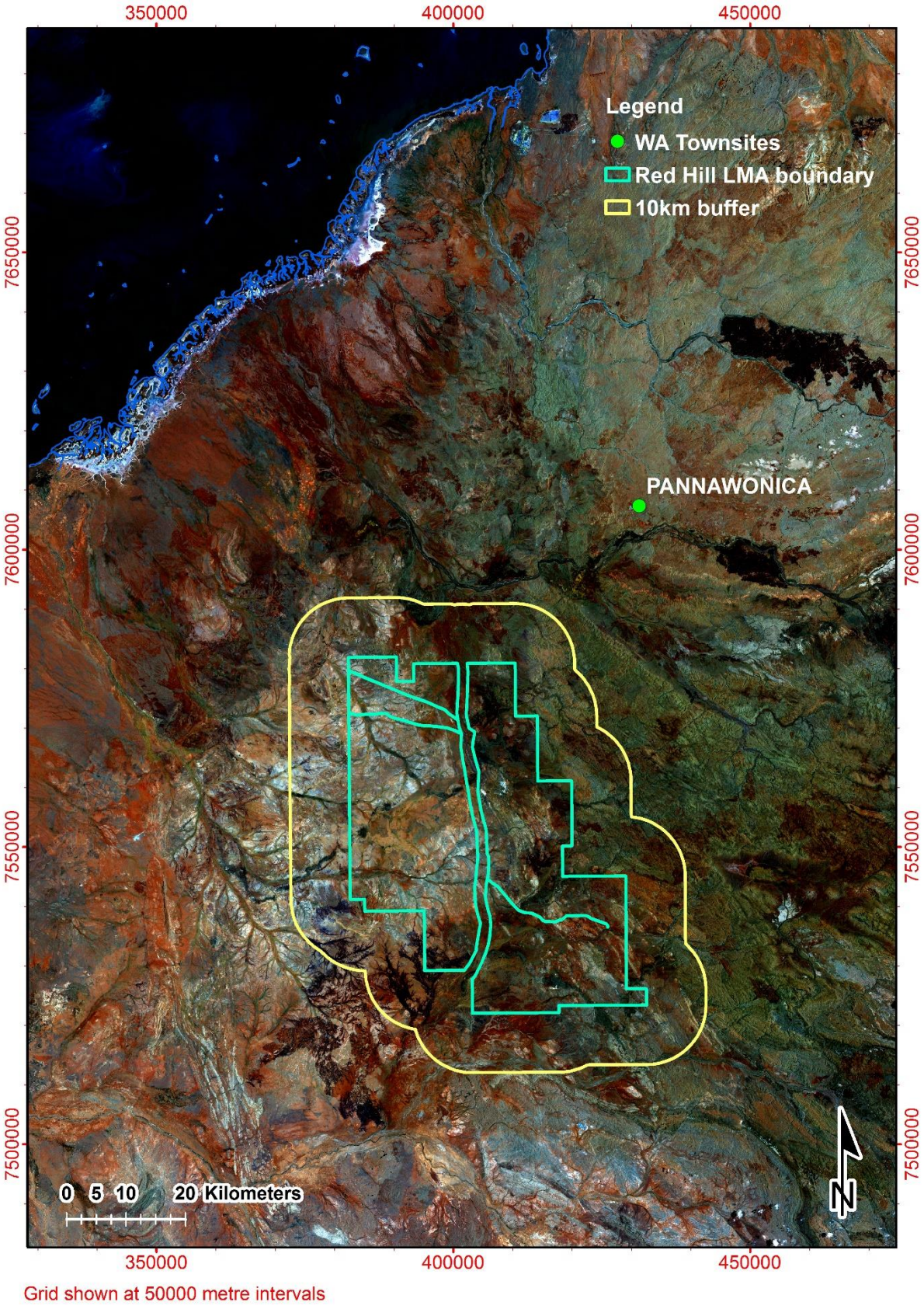

Figure 1 Red Hill Land Management Area, the background image is a Landsat 8 satellite image.

1 Data

Fire metrics were calculated using a combination of datasets provided by Rio Tinto and the Department of Biodiversity, Conservation and Attractions (DBCA). Table 2 displays the datasets used.

Table 2 Datasets used in the Red Hill fire metric analysis.

Dataset	Source	Description
Final Red Hill NQ POP habitat combined_region.shp	Rio Tinto	Northern Quoll and Pilbara Olive Python habitat extent
2016_Red Hill_LandSystems_exported.shp	Rio Tinto	Land system boundaries
Red Hill Station_exported.shp	Rio Tinto	Red Hill LMA boundary
Pilbara_fires_Z50_1999.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2001.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2003.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2004.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2006.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2007Oct.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2008.shp	DBCA	Fire scar boundaries
Pilbara_fires_Z50_2009.shp	DBCA	Fire scar boundaries
114075_2010-2011_FireScars.shp	DBCA	Fire scar boundaries
114075_2011-2012_FireScars.shp	DBCA	Fire scar boundaries
11475_2012-2013_FireScars.shp	DBCA	Fire scar boundaries
Fortescue_and_Offshore_Fires_2013_2014.shp	DBCA	Fire scar boundaries
Fortescue_River_Catchment_fire_mapping_2015.shp	DBCA	Fire scar boundaries
201516_Pilbara_Fire_Mapping_mga50.shp	DBCA	Fire scar boundaries
201617_114075_afed.shp	DBCA	Fire scar boundaries
114075_dec16_to_dec17_rio_2017_update.shp	DBCA	Fire scar boundaries
114075_160918_060119_mga50.shp	DBCA	Fire scar boundaries
RedHill_fires_201920_10kmbuff.shp	DBCA	Fire scar boundaries

1.1 Land Systems mapping

The land systems mapping dataset was provided by Rio Tinto. This dataset was used to calculate area based statistics for land systems within the Red Hill LMA. The total areas and the description for each land system are listed in Table 3 Figure 2 displays a map of Red Hill LMA and the supplied mapping.

Table 3 Land systems and area statements over the Red Hill Land Management Area.

Land system ID	Description	Area (hectares)
HOT	Houndstooth Land System	23,913.62
NNT	Nanutarra Land System	3,786.18
UAR	Uaroo Land System	10,457.67
DOR	Dollar Land System	8,743.59
SRK	Sherlock Land System	2,284.83
CPN	Capricorn Land System	31,381.91
RIV	River Land System	1,829.99
ROB	Robe Land System	12,587.46
BGD	Boolgeeda Land System	9,637.77
URY	Urandy Land System	11,172.49
STT	Stuart Land System	65,308.43
NEW	Newman Land System	807.88
ROC	Rocklea Land System	5,253.46
CAL	Calcrete Land System	542.02

1.2 Northern Quoll and Pilbara Olive Python boundary

An ESRI shapefile with the habitat extent of the Northern Quoll (NQ) and Pilbara Olive Python (POP) was provided by Rio Tinto. Mapped habitat for both NQ and POP is based on land system mapping (van Vreeswyk et al., 2004) and represents a coarse estimate of available habitat within the LMA. The total area of the fauna habitat covers 53,630 hectares of Red Hill LMA. Figure 2 displays a map of the fauna habitat within Red Hill LMA. Throughout this document the habitat area for the fauna will be referred to as the NQ and POP habitat.

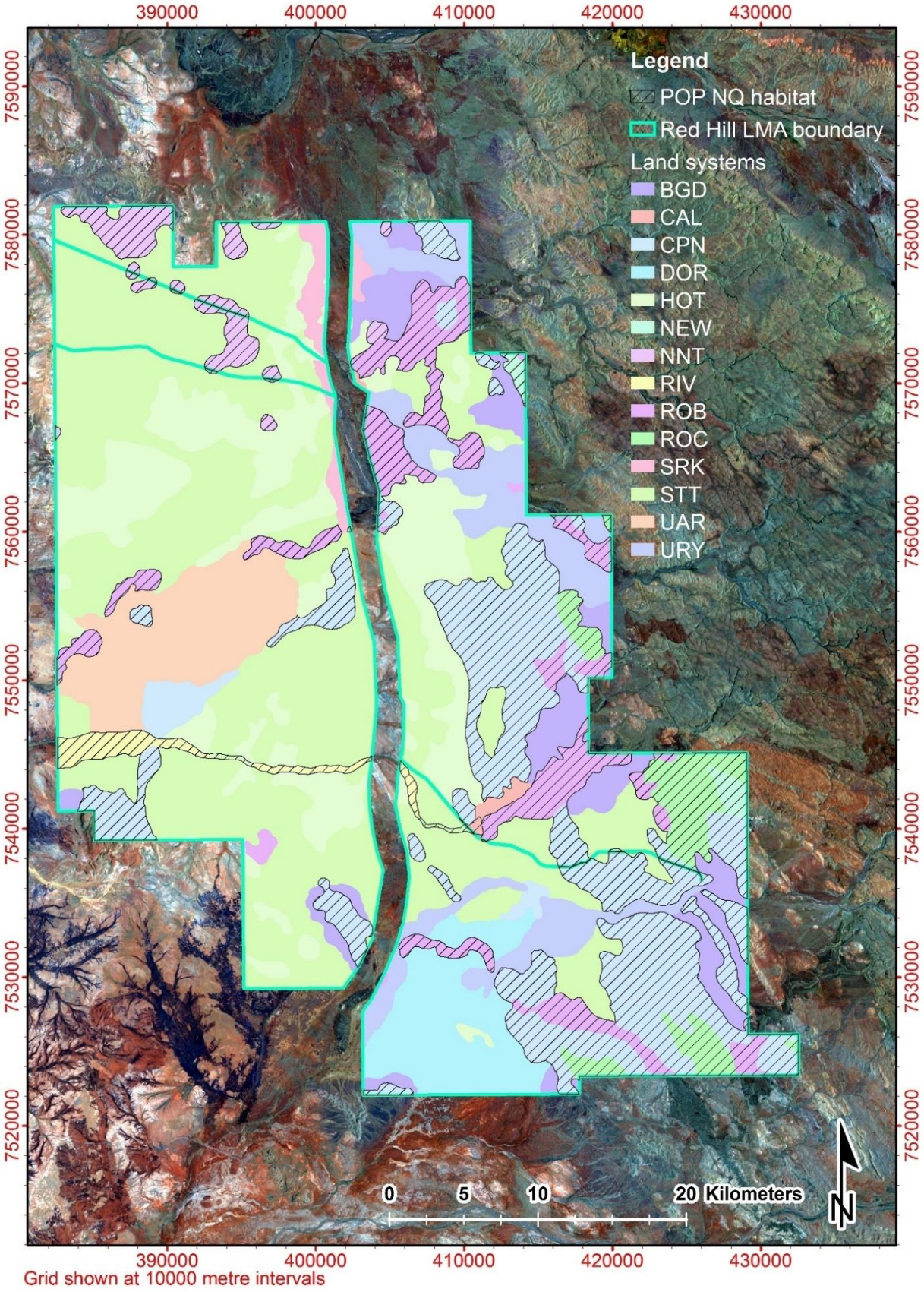

Figure 2 Red Hill Land Management Area with land systems and Northern Quoll and Pilbara Olive Python habitat boundary, the background image is a Landsat 8 satellite image.

2 Methodology

The methodology describes the calculation of the fire metrics.

2.1 Fire metrics

Metrics were derived from the fire scar datasets using ArcGIS 10.6.1. This software is geographic information systems software that allows the viewing, analysis and storage of spatial data.

2.1.1 Vector data cleaning

Fire scar vectors were examined for errors in the data, which might cause errors in the area statistics. Duplicate polygons can sometimes occur when the same fire is mapped more than once, this is more common around the edges of Landsat scene boundaries. To find duplicate polygons within each year of fire scar mapping the “Count Overlapping Polygons” toolbox in ArcGIS was used (Honeycutt, 2012). Duplicate polygons were then deleted. Part of the cleaning process was to ensure all data were in the same coordinate system and that all datasets had been repaired using the “Repair Geometry” tool in ArcGIS.

Once all the individual years of fire scar datasets were cleaned they were merged into one shapefile and clipped to the Red Hill LMA 10km buffer shapefile using the “Clip” tool in ArcGIS. This dataset was further clipped to the Red Hill LMA area of interest.

2.1.2 Graphing fire metrics

Graphs were produced using the statistical package R. This enables repeatability in the graphing as a script has been produced for each graph set up and annual updates require the latest data to be entered (R Core Team, 2017).

3 Results

The results address the fire metrics requested and listed in Table 1. The results are structured according to Table 4

Table 4 Structure of the fire metrics results.

Metric	**Category**	**Graphs/ tables**
3.1 Total area (ha) and proportion burned each year.	3.1.1 Across entire study area	Table 6 Figure 4 and Figure 5
	3.1.1 Within mapped NQ & POP habitat	Table 6 and Table 7 and Figure 5
	3.1.2 Within land systems	Table 7 and Table 8 Figure 6 and Figure 7 Alternative style graphs: Figure 8 and Figure 9 Individual land systems graphs: Figures 10 - 23

To provide context of each variable across the Red Hill LMA the area of the study site, POP and NQ habitat and land systems that fire metrics were calculated for are displayed in Table 5.

Table 5 Area statistics for each zone; area statements were used to calculate metrics based on these zones.

Zone	Total area (ha)	% of study area
Red Hill LMA	187,707.80	100
POP NQ Habitat	53,629.72	28.57
HOT	23,913.62	12.74
NNT	3,786.18	2.02
UAR	10,457.67	5.57
DOR	8,743.59	4.66
SRK	2,284.83	1.22
CPN	31,381.91	16.72
RIV	1,829.99	0.97
ROB	12,587.46	6.71
BGD	9,637.77	5.13
URY	11,172.49	5.95
STT	65,308.43	34.79
NEW	807.88	0.43
ROC	5,253.46	2.80
CAL	542.02	0.29

3.1 Total area and proportion burned in each fire mapping year

The following statistics show total area burnt in hectares for each year of available fire mapping. A variety of graphs and tables are presented for each fire metric to allow for different options to be explored. Metrics calculated are provided as;

Total area (ha) and proportion burned each year:

- across the entire study area
- within mapped NQ and POP habitat
- within land systems

Fires that occurred on Red Hill station and within a 10km buffer are shown in Figure 3.

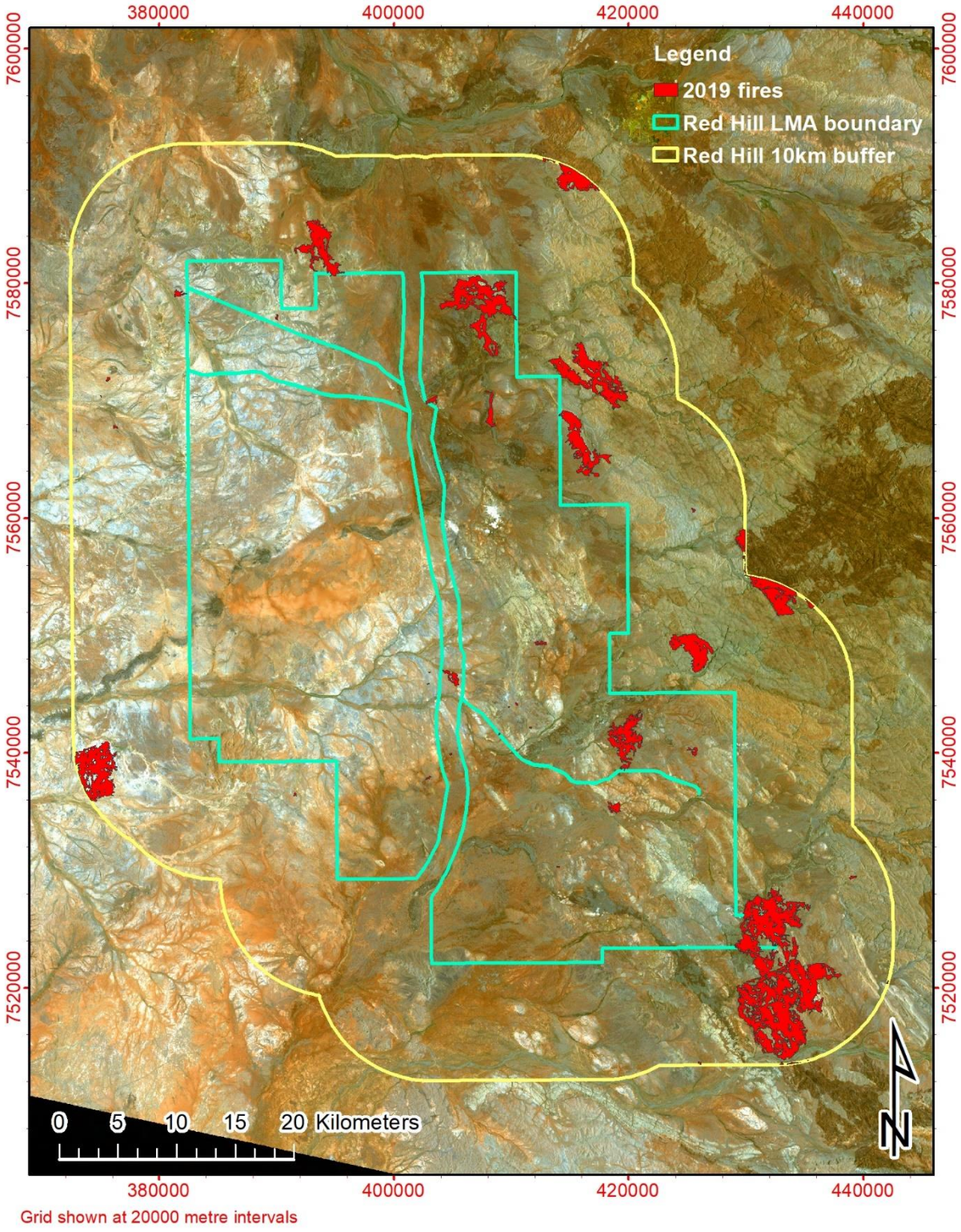

Figure 3 Fires that occurred on Red Hill Station and within a 10 km buffer in 2019, the background image is a Landsat 8 satellite image, the image date is 24th December 2019 and was used to map the 2019 fires.

3.1.1 Across Red Hill LMA and mapped NQ & POP habitat

The NQ and POP habitat and total Red Hill area metrics have been combined in both the tables and figures as the NQ and POP habitat is a subset of the total area and this reduces the number of tables, graphs and figures. Table 6 displays the total area of land mapped as burnt over Red Hill and the NQ and POP habitat. The percentages based on these area figures are also displayed in Table 6. Graphs of the area statements are displayed in Figure 4 and percentages values are displayed in Figure 5.

Table 6 Total area and percentage of land burnt (ha) over Red Hill LMA and NQ & POP habitat for each year of available fire mapping.

YEAR	1999	2001	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
TOTAL AREA BURNT (HA)	4,490	55,748	18,367	296	20,384	3,305	2,062	19,456	391	1,719	2,524	10,524	8,154	9,875	11,524	3,129	19,053	2,681
% BURNT	2	30	10	<1	11	2	1	10	<1	1	1	6	4	5	6	2	10	1
TOTAL AREA NQ/POP HABITAT BURNT (HA)	1,130	20,238	1,867	31	2,234	1,916	431	8,101	0	347	1,185	1,330	2,709	6,540	4,919	922	3,218	1,250
% BURNT	2	38	3	0	4	4	1	15	0	1	2	2	5	12	9	2	6	2

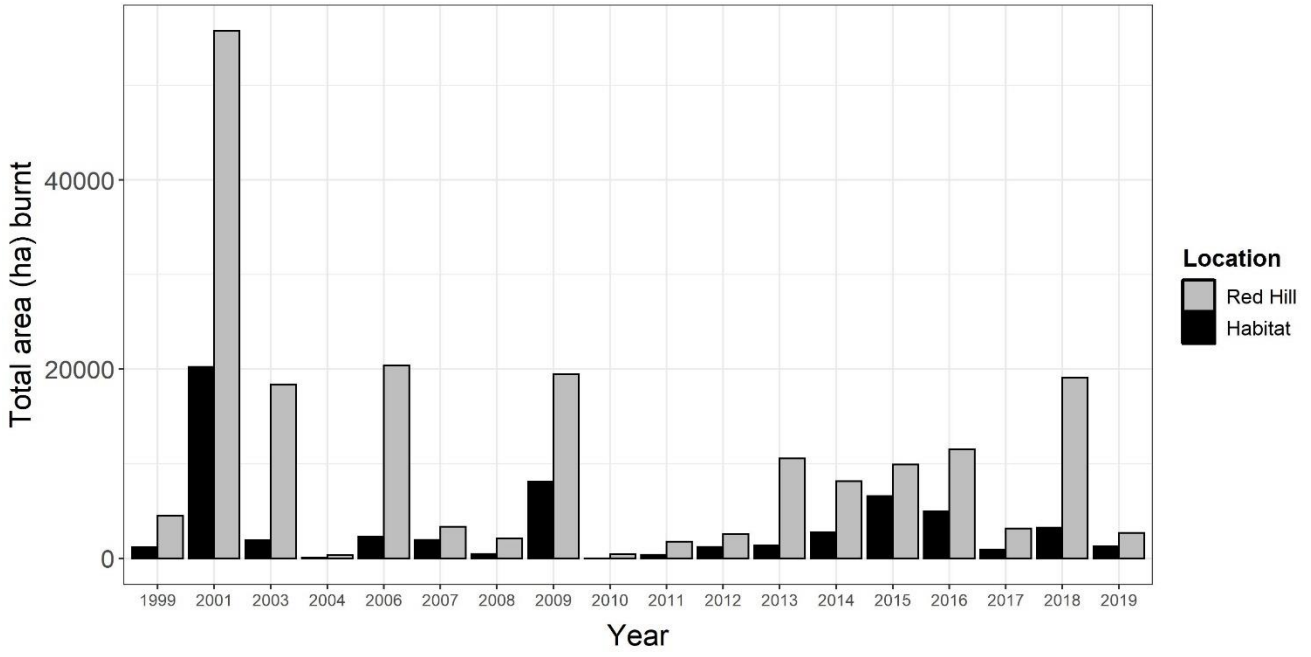

Figure 4 Total area (ha) burnt per year across Red Hill LMA and NQ & POP habitat.

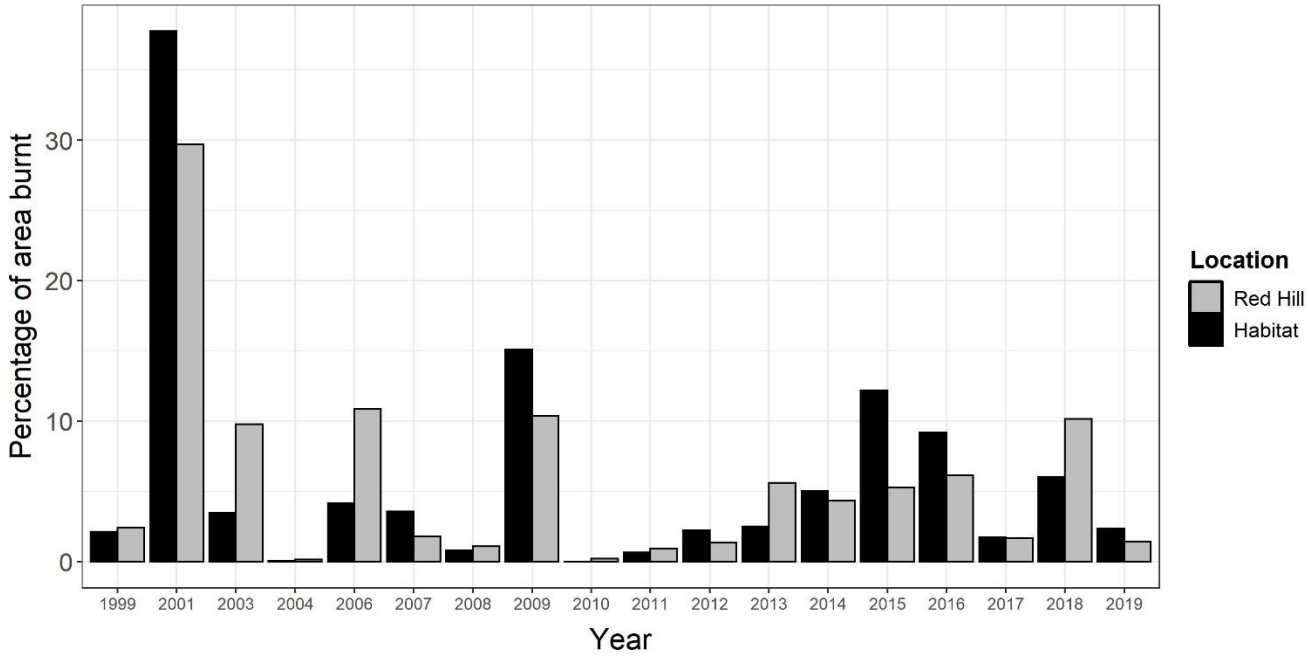

Figure 5 Total percentage burnt per year across Red Hill LMA and NQ & POP habitat range.

3.1.2 Land systems

Table 7 displays the total area of land mapped as burnt across the different land system units. The percentages based on these area figures are displayed in Table 8. Graphs of the area statements are displayed in Figure 6 and percentages of those figures are displayed in Figure 7. Alternative graphs for displaying the metrics for the land systems across Red Hill LMA are displayed in Figure 8 and Figure 9. These display the same data but give an alternative visual representation.

Table 7 Total area in hectares of area burnt over Red Hill LMA within the land systems for each year of available fire mapping.

YEAR	1999	2001	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
HOT	276	5,830	2,673	27	3,858	0	841	503	0	152	943	1,252	1,795	194	1,696	179	3,141	20
NNT	0	1,259	912	0	133	0	0	786	0	323	0	0	168	0	34	3	43	3
UAR	339	43	0	0	1,149	0	0	2,971	0	0	0	1,686	4	3	107	<1	3,821	0
DOR	0	5,071	0	0	0	27	80	0	0	0	0	1,296	88	0	0	<1	789	0
SRK	6	69	1,329	0	248	0	2	148	129	48	0	0	313	0	584	0	299	0
CPN	94	11,457	231	1	1,589	757	102	2,511	0	20	1,153	1,165	2,124	5,701	2,035	766	1,371	809
RIV	0	25	0	0	123	0	7	315	0	0	0	0	0	50	208	19	127	0
ROB	996	3,627	506	29	481	455	319	4,087	0	3	0	870	418	232	915	136	1,170	366
BGD	619	3,659	1,100	0	202	670	24	1,099	0	62	0	579	93	1,315	999	447	598	500
URY	200	5,581	1,194	239	1,000	0	317	2,648	261	5	86	1,095	281	1,074	284	13	1,052	499
STT	1,920	15,080	10,166	0	11,355	691	423	3,768	0	1,105	310	2,291	2,870	710	2,932	1,559	6,186	396
NEW	0	415	42	0	13	1	0	307	0	0	0	0	0	139	357	0	0	2
ROC	40	3611	206	0	235	703	0	207	0	0	32	23	0	400	1,360	0	455	72
CAL	0	21	7	0	0	0	26	25	0	0	0	268	0	58	14	6	0	14

Table 8 Total percentage of area burnt over Red Hill LMA within the land systems for each year of available fire mapping.

YEAR	1999	2001	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
HOT	1	24	11	<1	16	0	4	2	0	1	4	5	8	1	7	1	13	<1
NNT	0	33	24	0	4	0	0	21	0	9	0	0	4	0	1	<1	1	<1
UAR	3	<1	0	0	11	0	0	28	0	0	0	16	<1	<1	1	<1	37	0
DOR	0	58	0	0	0	<1	1	0	0	0	0	15	1	0	<1	<1	9	0
SRK	<1	3	58	0	11	0	<1	6	6	2	0	0	14	0	26	0	13	0
CPN	<1	37	1	<1	5	2	<1	8	0	0	4	4	7	18	6	2	4	3
RIV	0	1	0	0	7	0	<1	17	0	0	0	0	0	3	11	1	7	0
ROB	8	29	4	<1	4	4	3	32	0	<1	0	7	3	2	7	1	9	3
BGD	6	38	11	0	2	7	<1	11	0	1	0	6	1	14	10	5	6	5
URY	2	50	11	2	9	0	3	24	2	<1	1	10	3	10	3	<1	9	4
STT	3	23	16	0	17	1	1	6	0	2	<1	4	4	1	4	2	9	1
NEW	0	51	5	0	2	<1	0	38	0	0	0	0	0	17	44	0	0	<1
ROC	1	69	4	0	4	13	0	4	0	0	1	<1	0	8	26	0	9	1
CAL	0	4	1	0	0	0	5	5	0	0	0	49	0	11	3	1	0	3

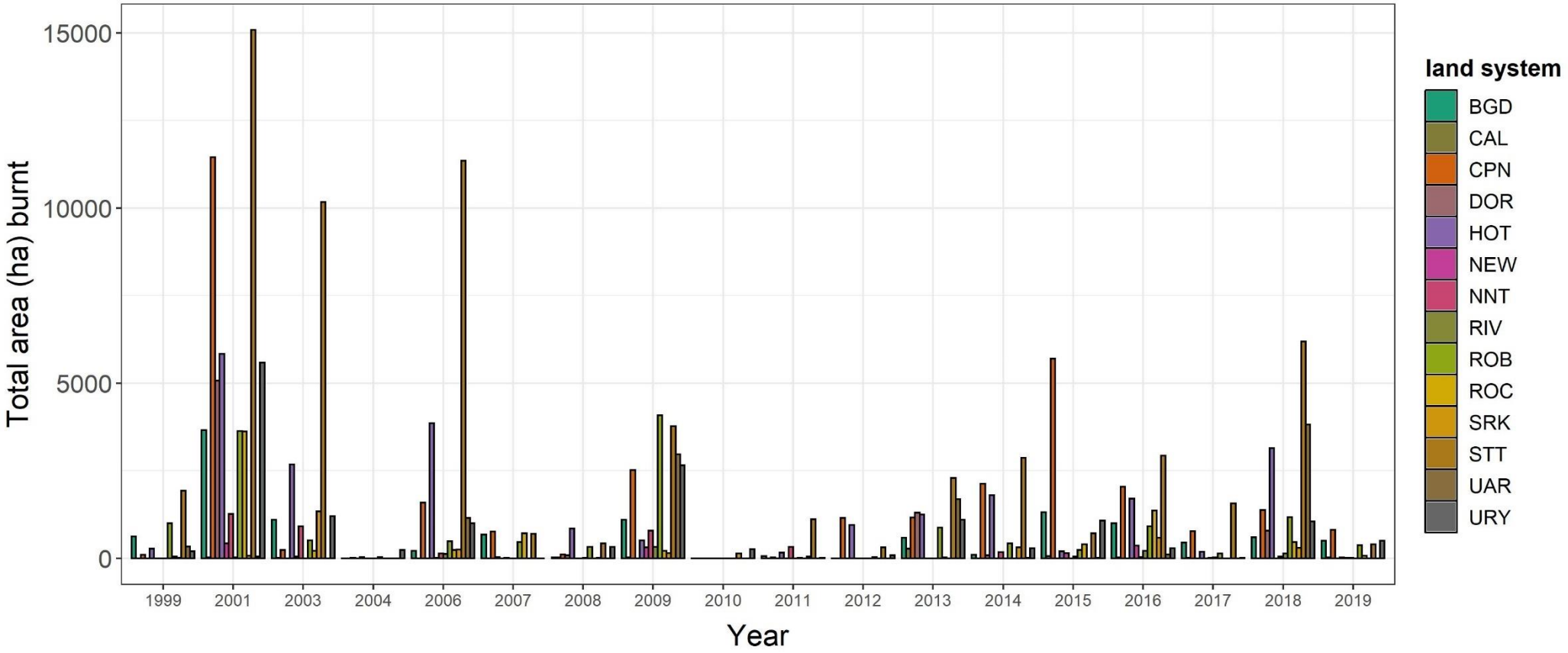

Figure 6 Total area (ha) burnt per year across Red Hill LMA land systems for each year of available fire mapping.

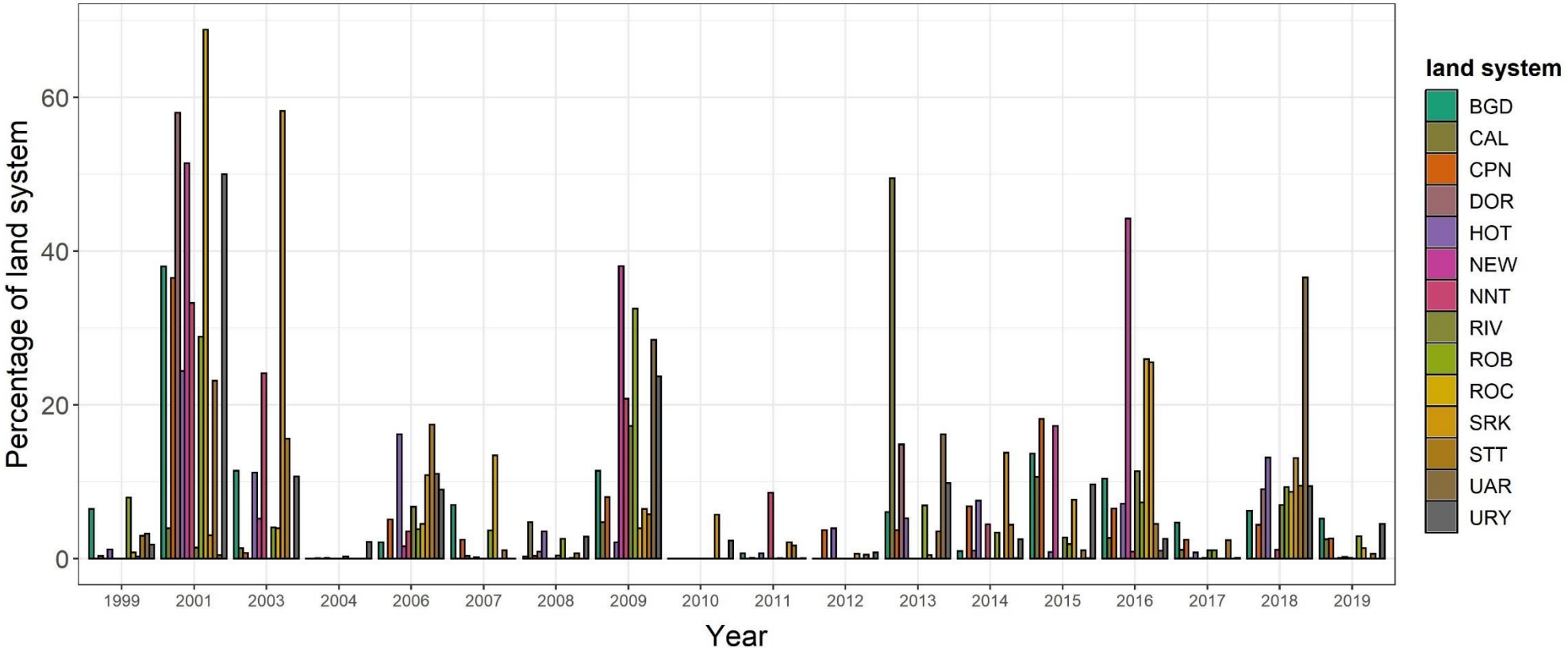

Figure 7 Total percentage burnt per year across Red Hill LMA land systems for each year of available fire mapping.

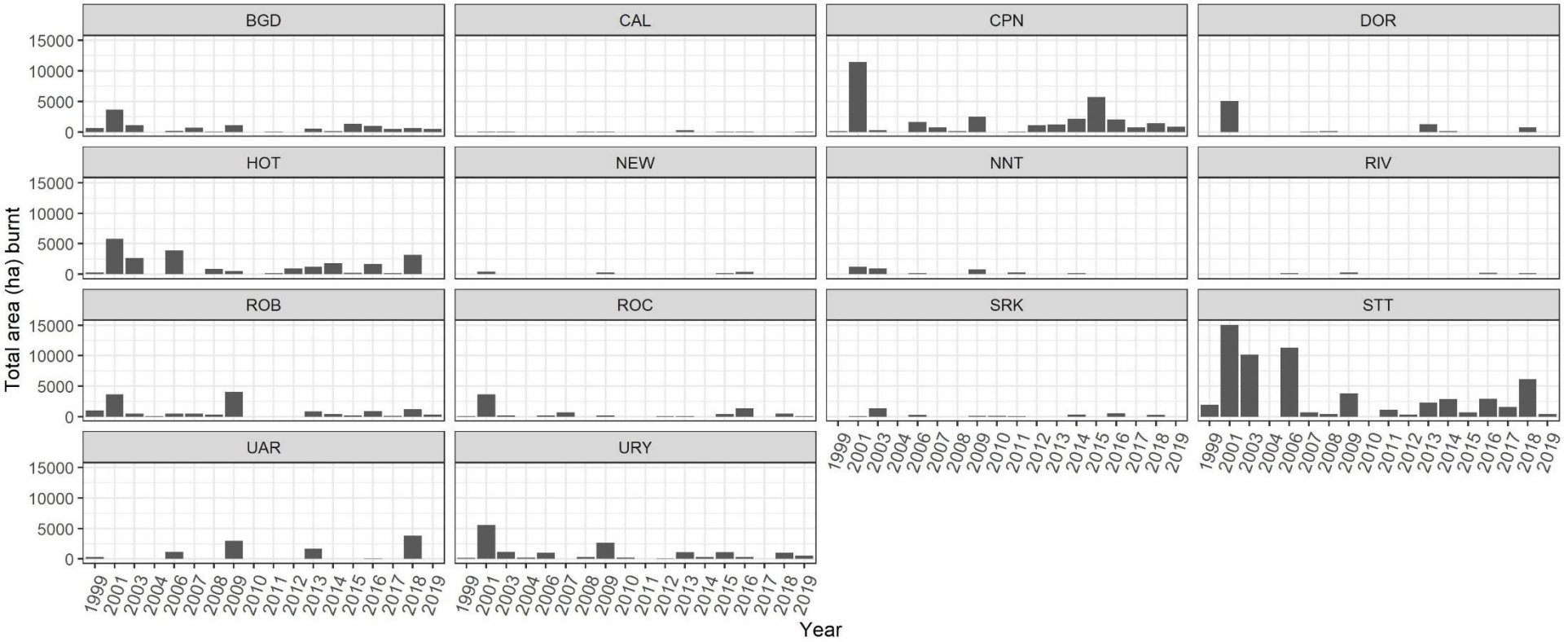

Figure 8 Alternative graph for total area (ha) burnt per year across Red Hill LMA land systems for each year of available fire mapping.

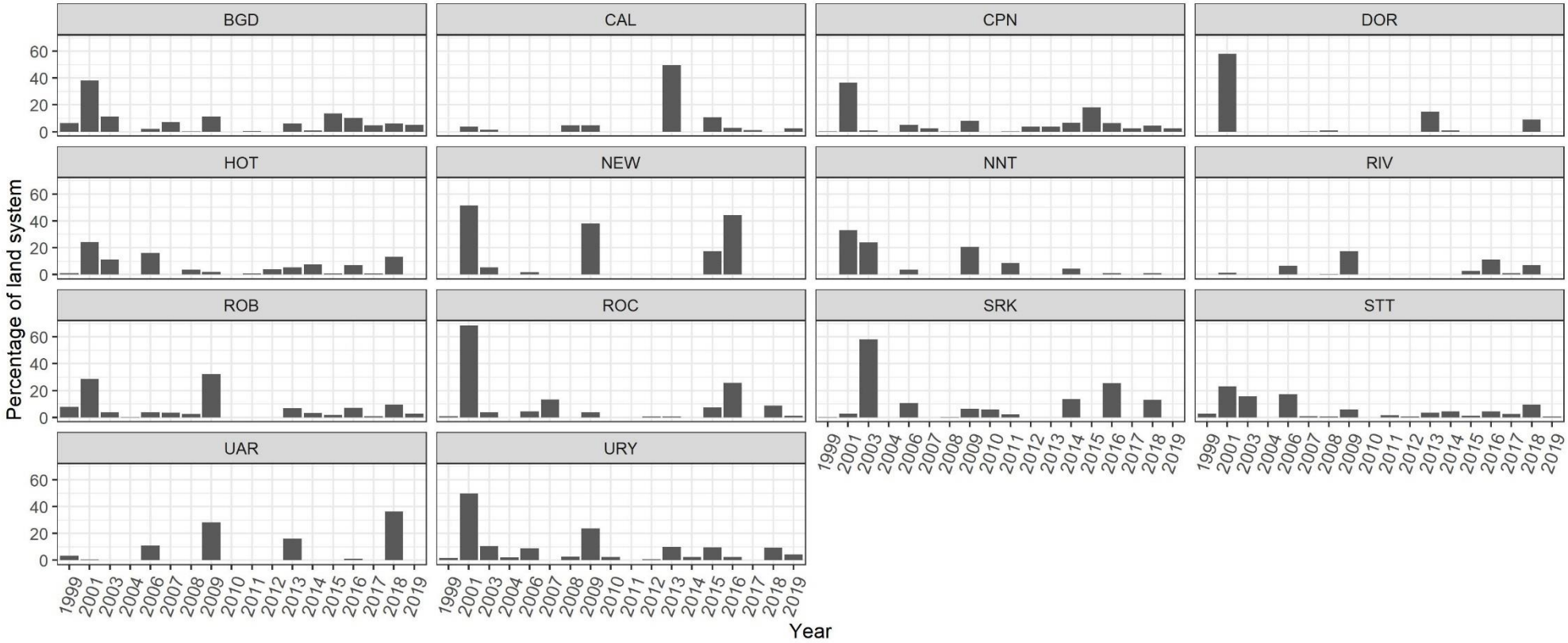

Figure 9 Alternative graph for total percentage burnt per year across Red Hill LMA land systems for each year of available fire mapping.

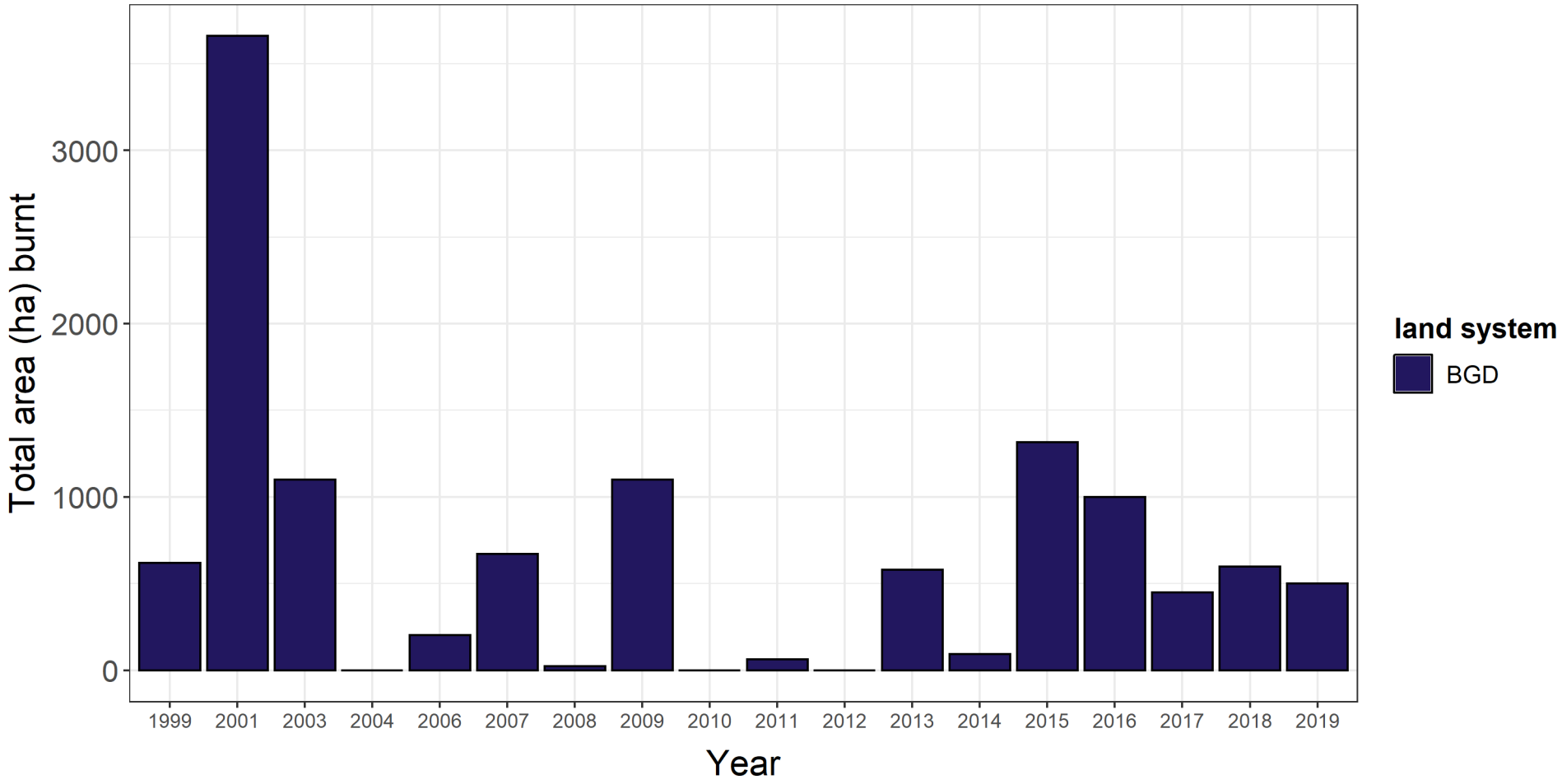

Figure 10 Total area (ha) burnt per year across the Boolgeeda land system for each year of available fire mapping.

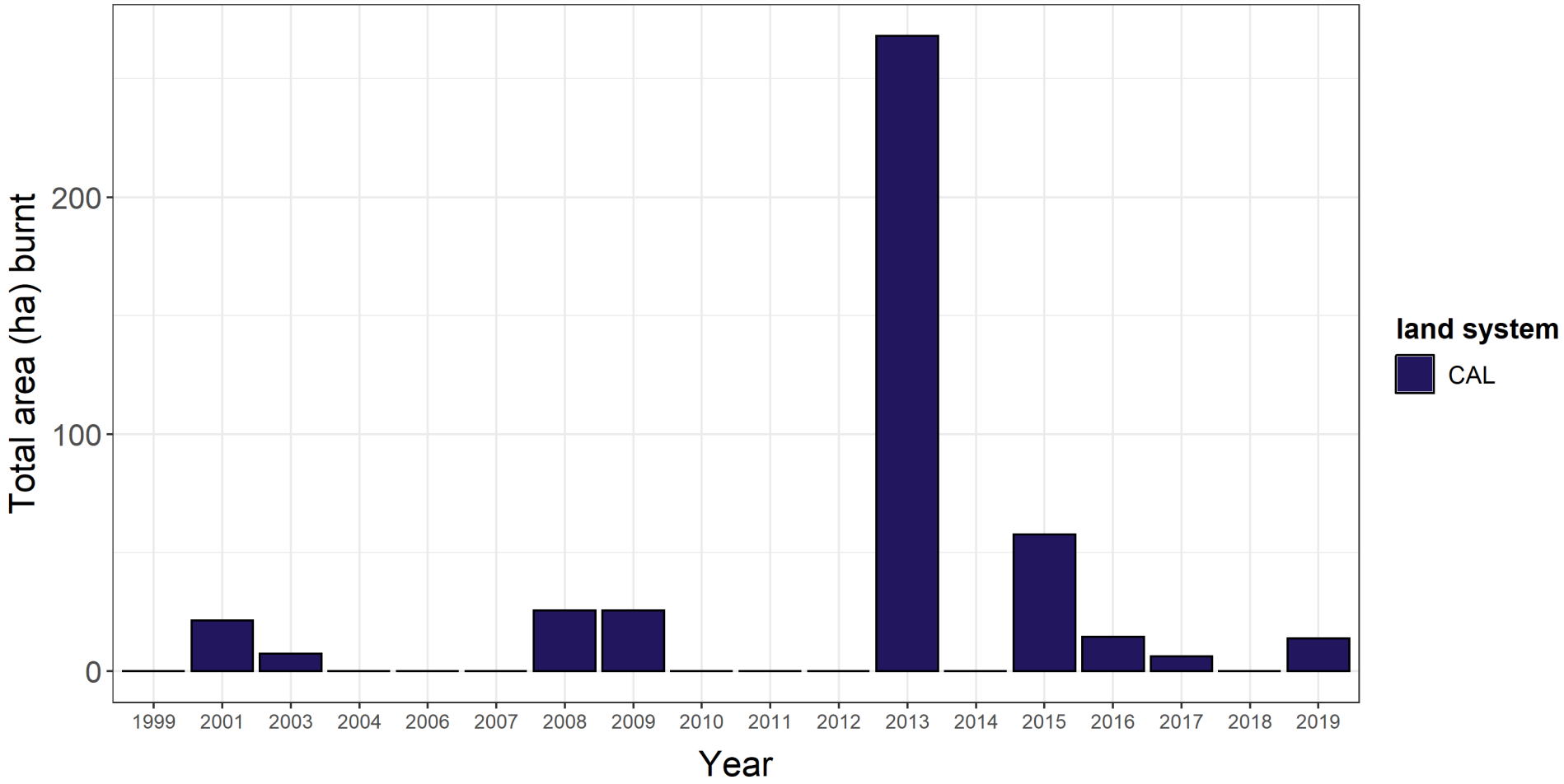

Figure 11 Total area (ha) burnt per year across the Calcrete land system for each year of available fire mapping.

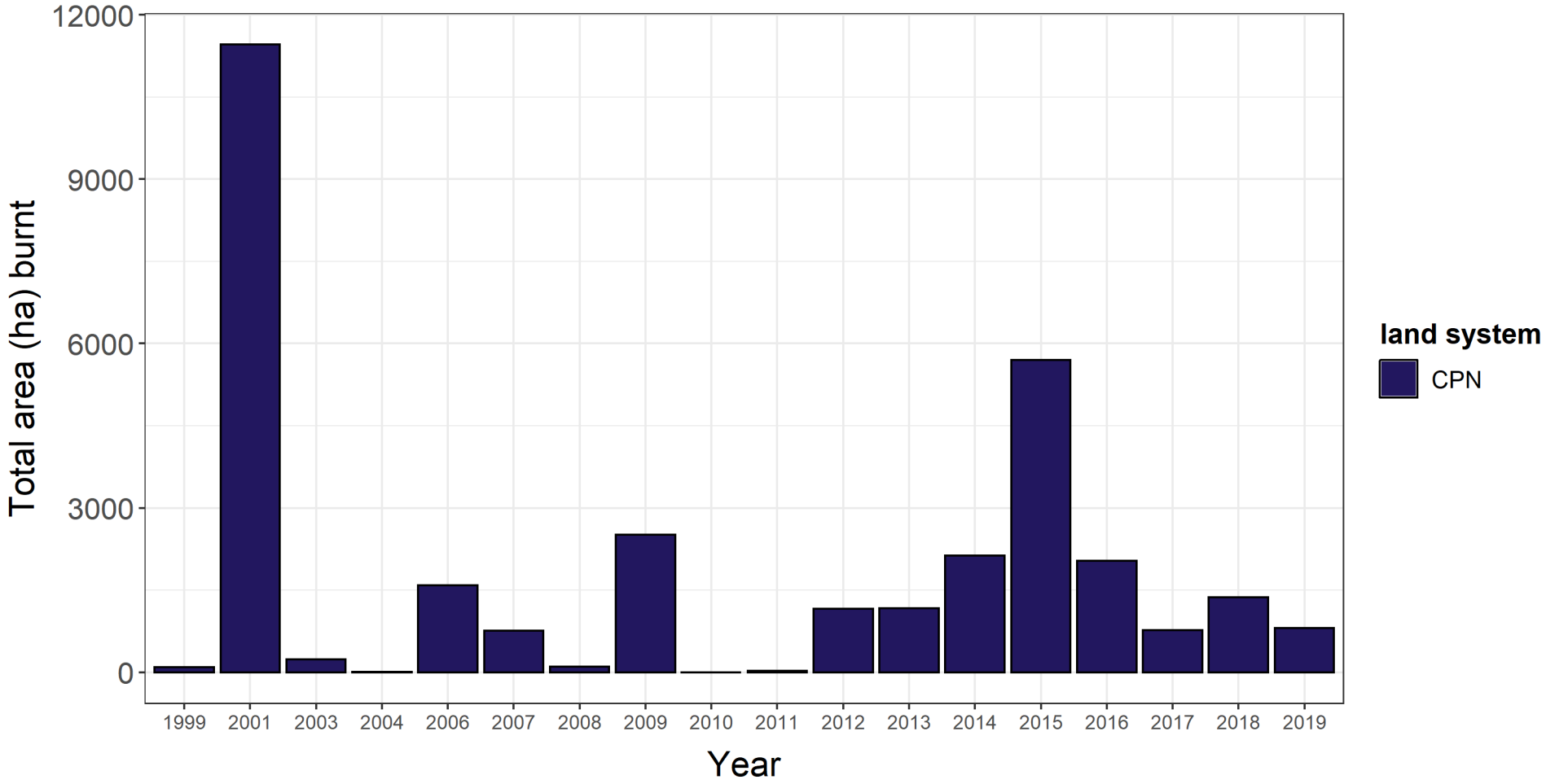

Figure 12 Total area (ha) burnt per year across the Capricorn land system for each year of available fire mapping.

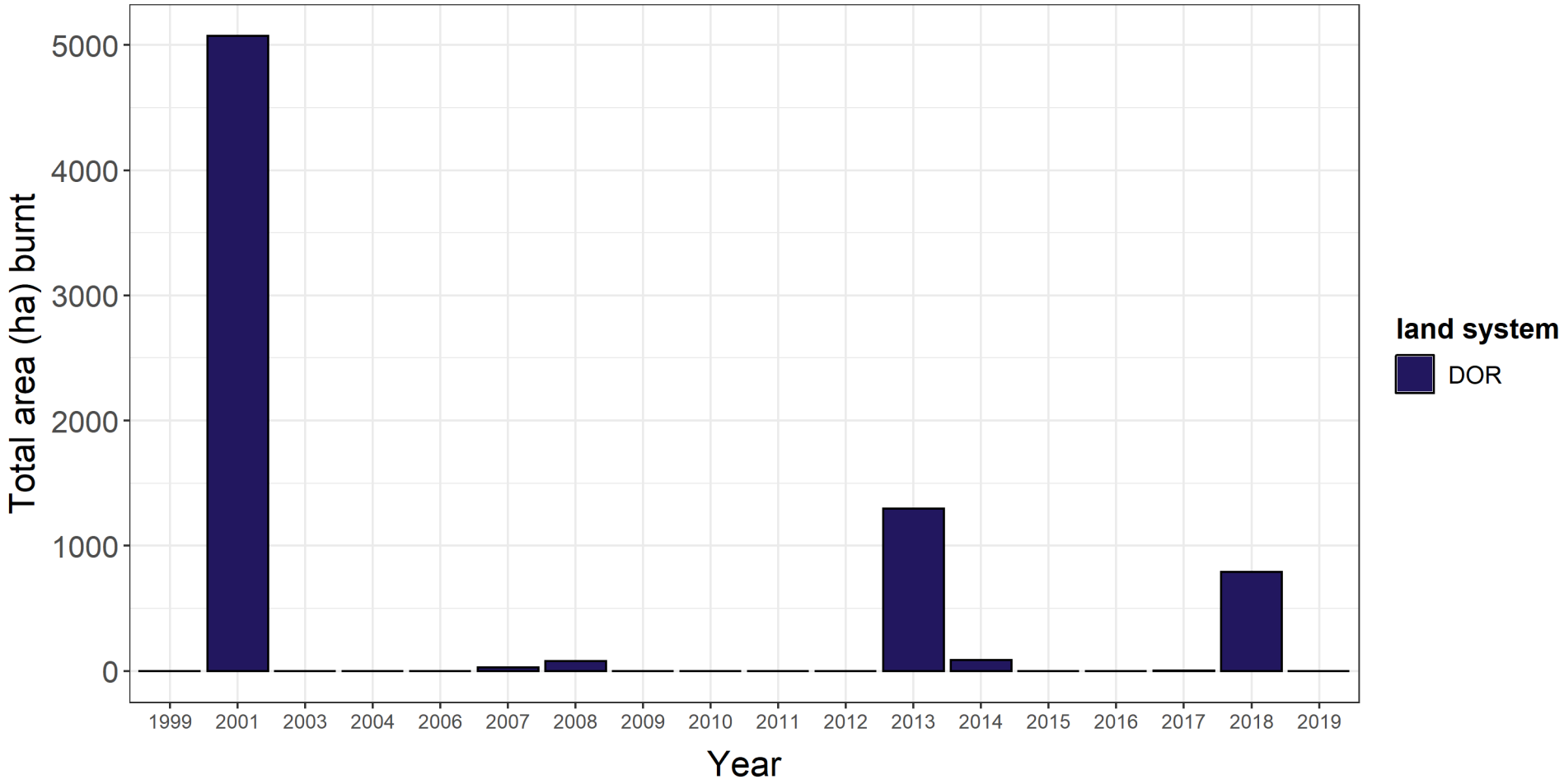

Figure 13 Total area (ha) burnt per year across the Dollar land system for each year of available fire mapping.

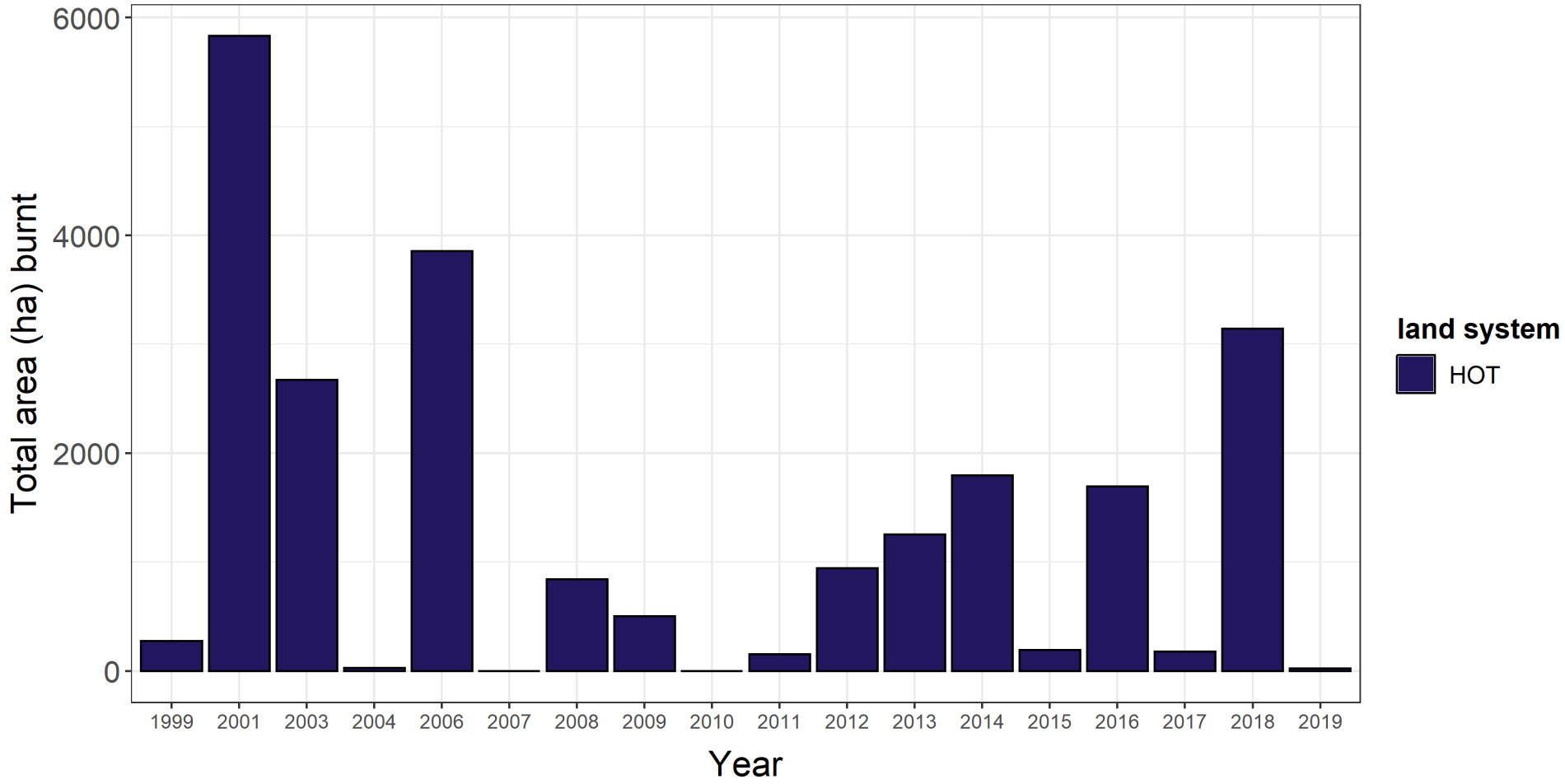

Figure 14 Total area (ha) burnt per year across the Houndstooth land system for each year of available fire mapping.

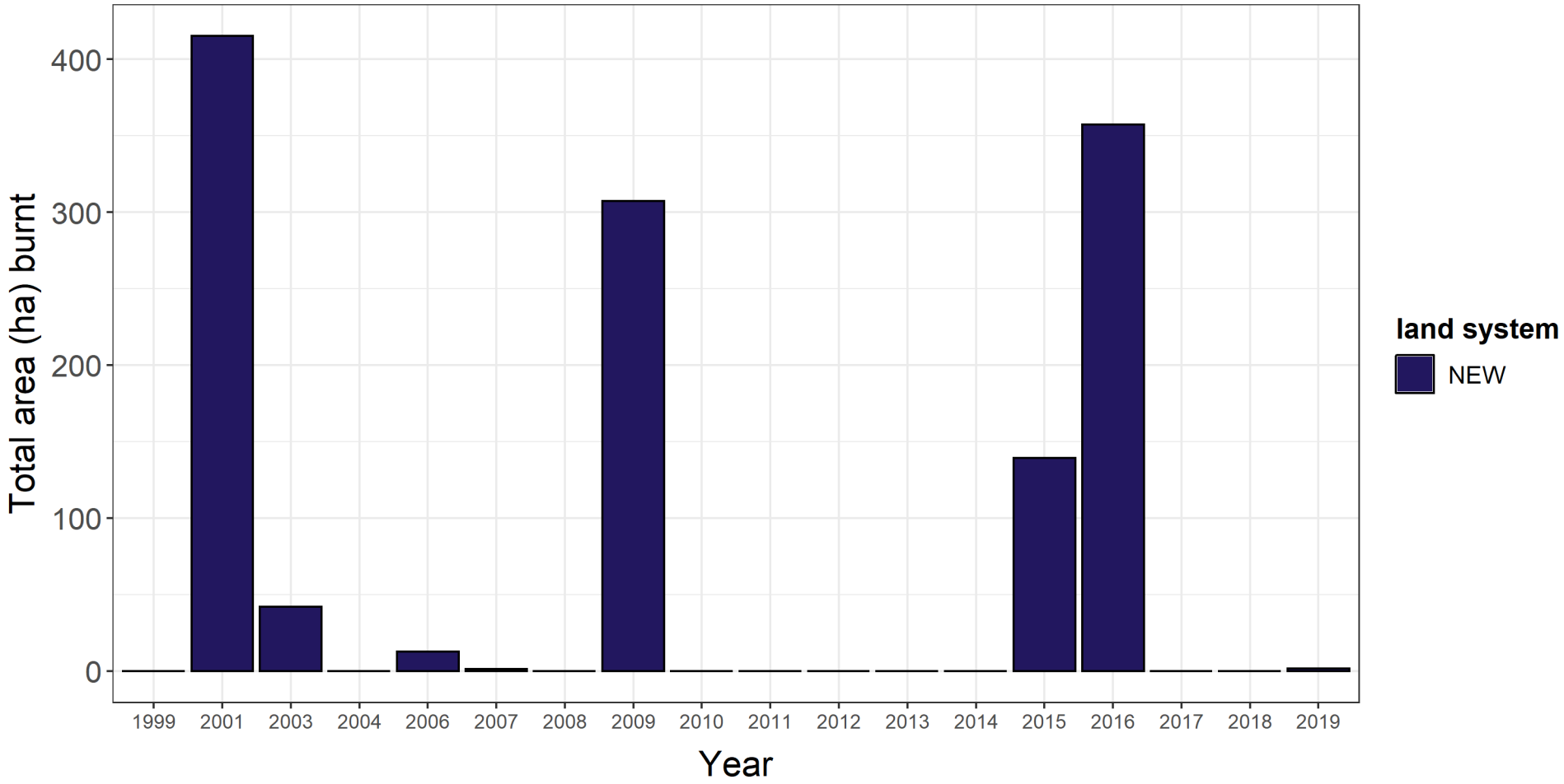

Figure 15 Total area (ha) burnt per year across the Newman land system for each year of available fire mapping.

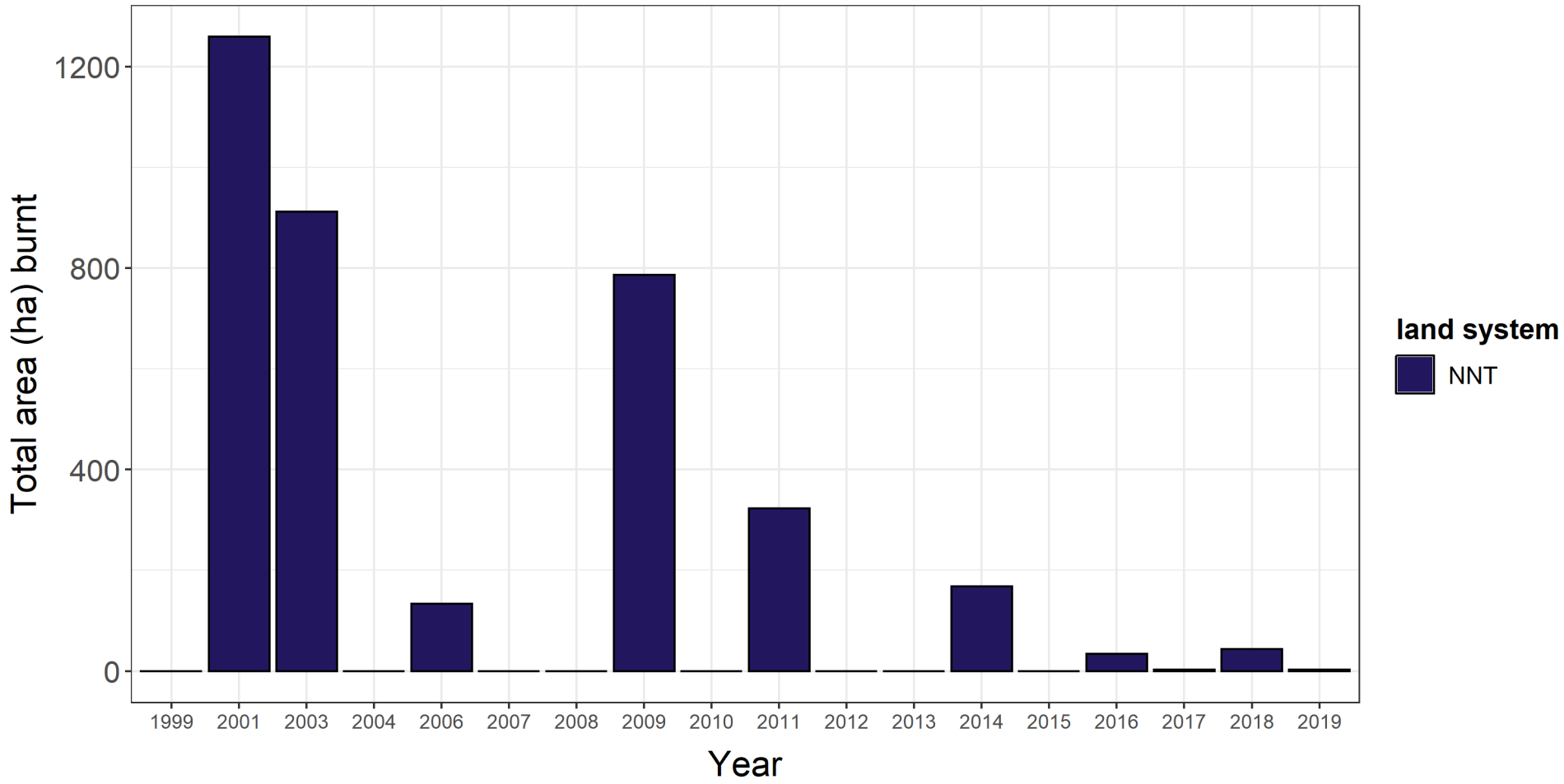

Figure 16 Total area (ha) burnt per year across the Nanutarra land system for each year of available fire mapping.

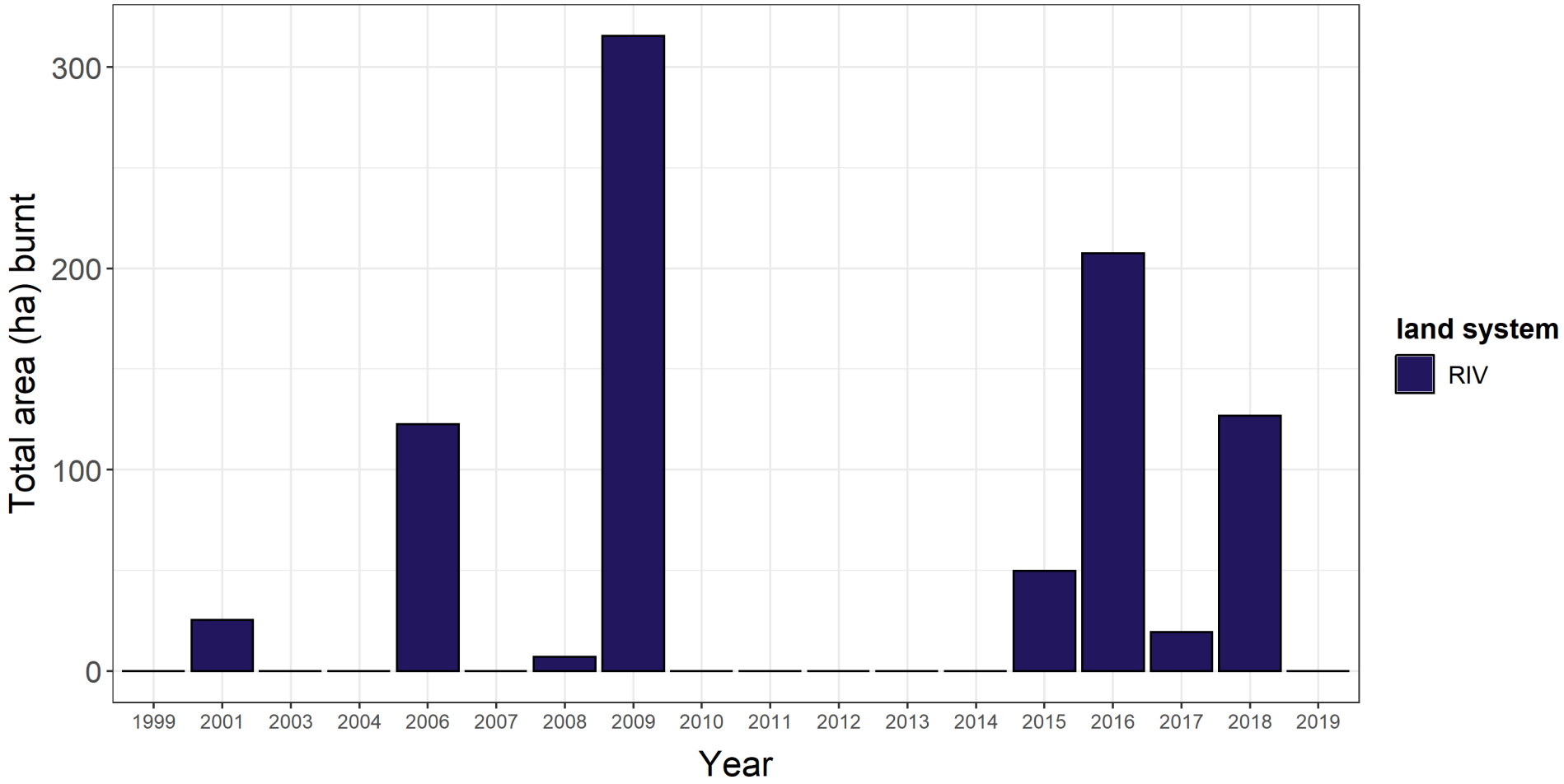

Figure 17 Total area (ha) burnt per year across the River land system for each year of available fire mapping.

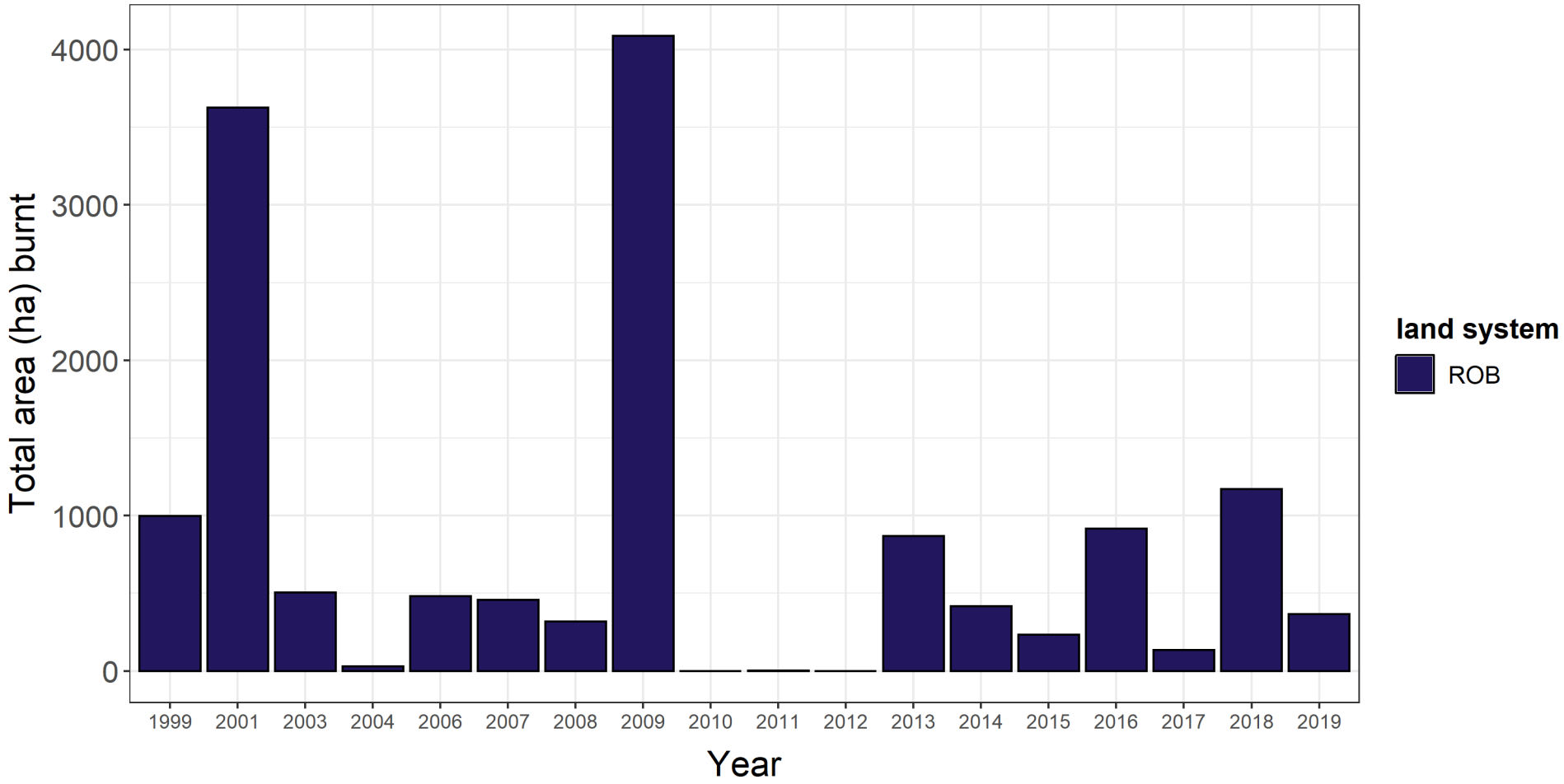

Figure 18 Total area (ha) burnt per year across the Robe land system for each year of available fire mapping.

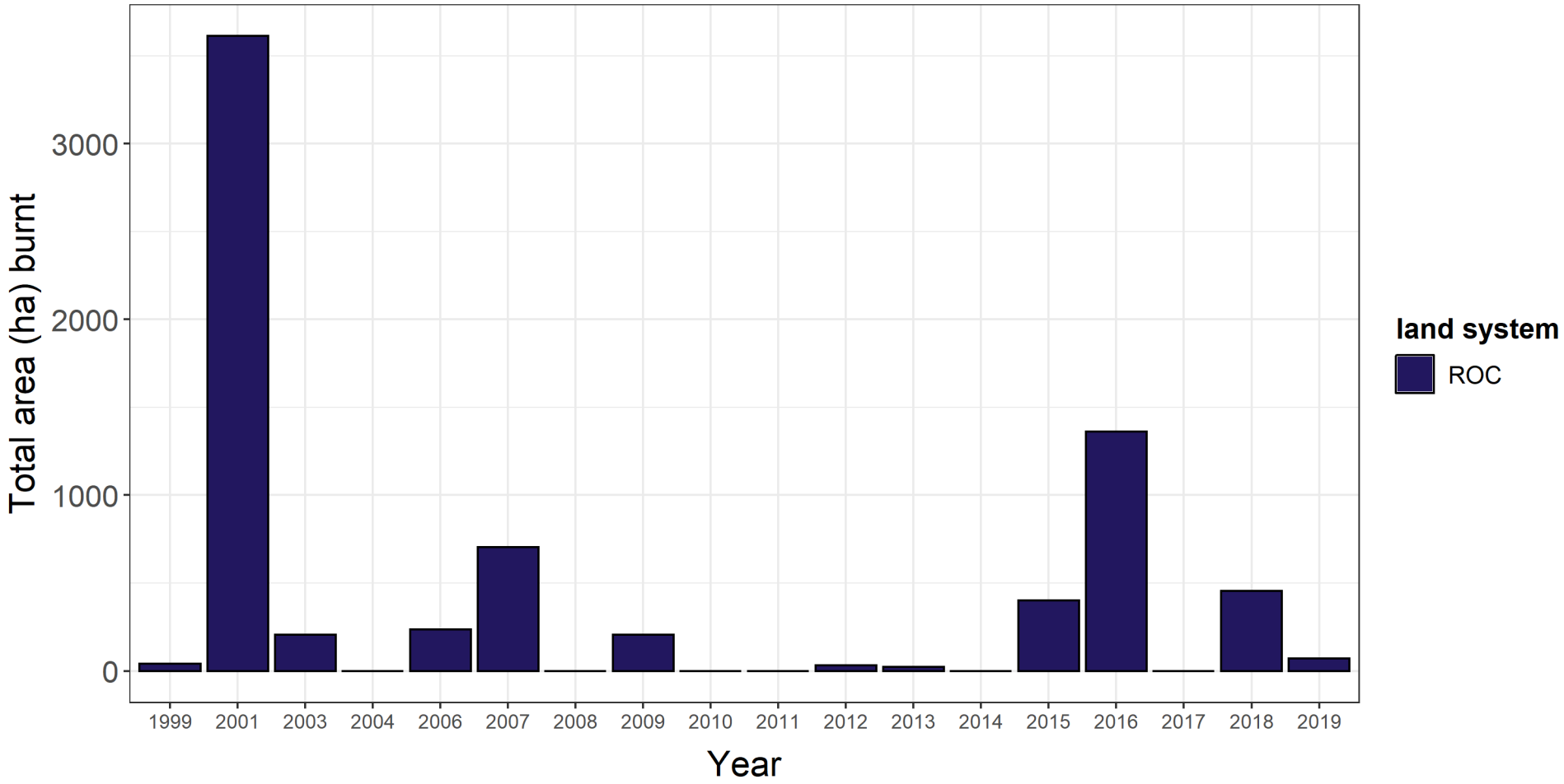

Figure 19 Total area (ha) burnt per year across the Rocklea land system for each year of available fire mapping.

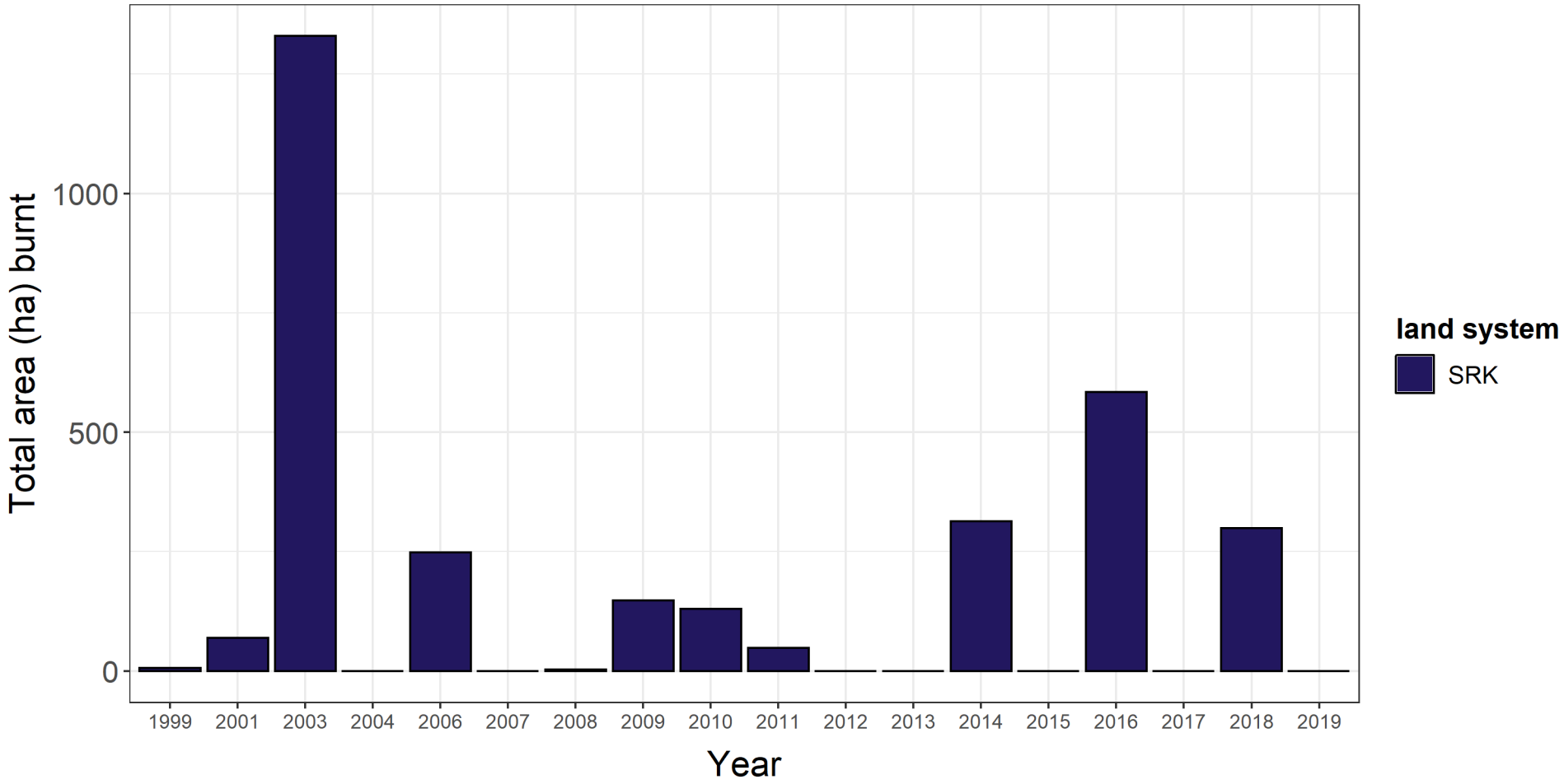

Figure 20 Total area (ha) burnt per year across the Sherlock land system for each year of available fire mapping.

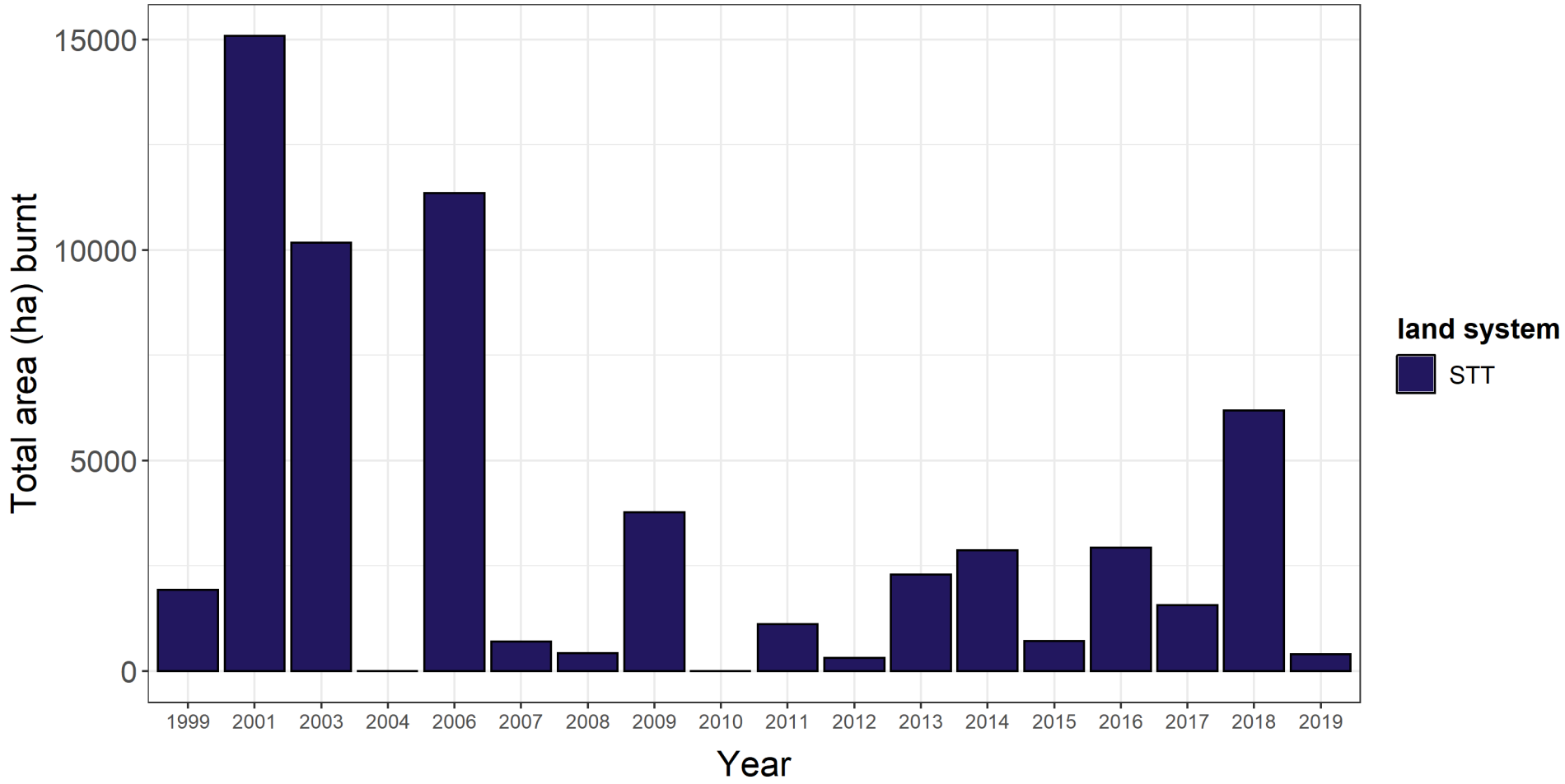

Figure 21 Total area (ha) burnt per year across the Stuart land system for each year of available fire mapping.

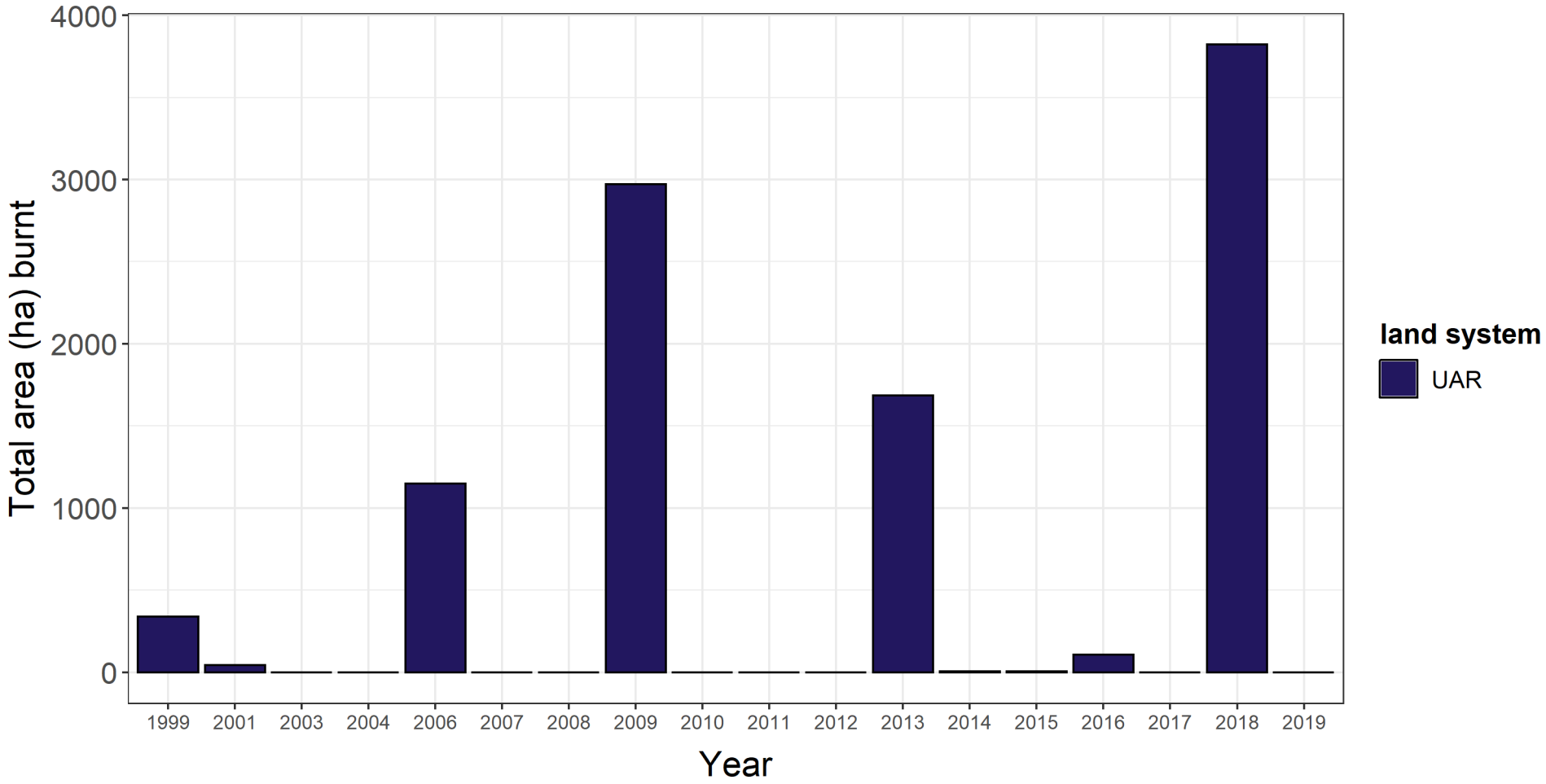

Figure 22 Total area (ha) burnt per year across the Uaroo land system for each year of available fire mapping.

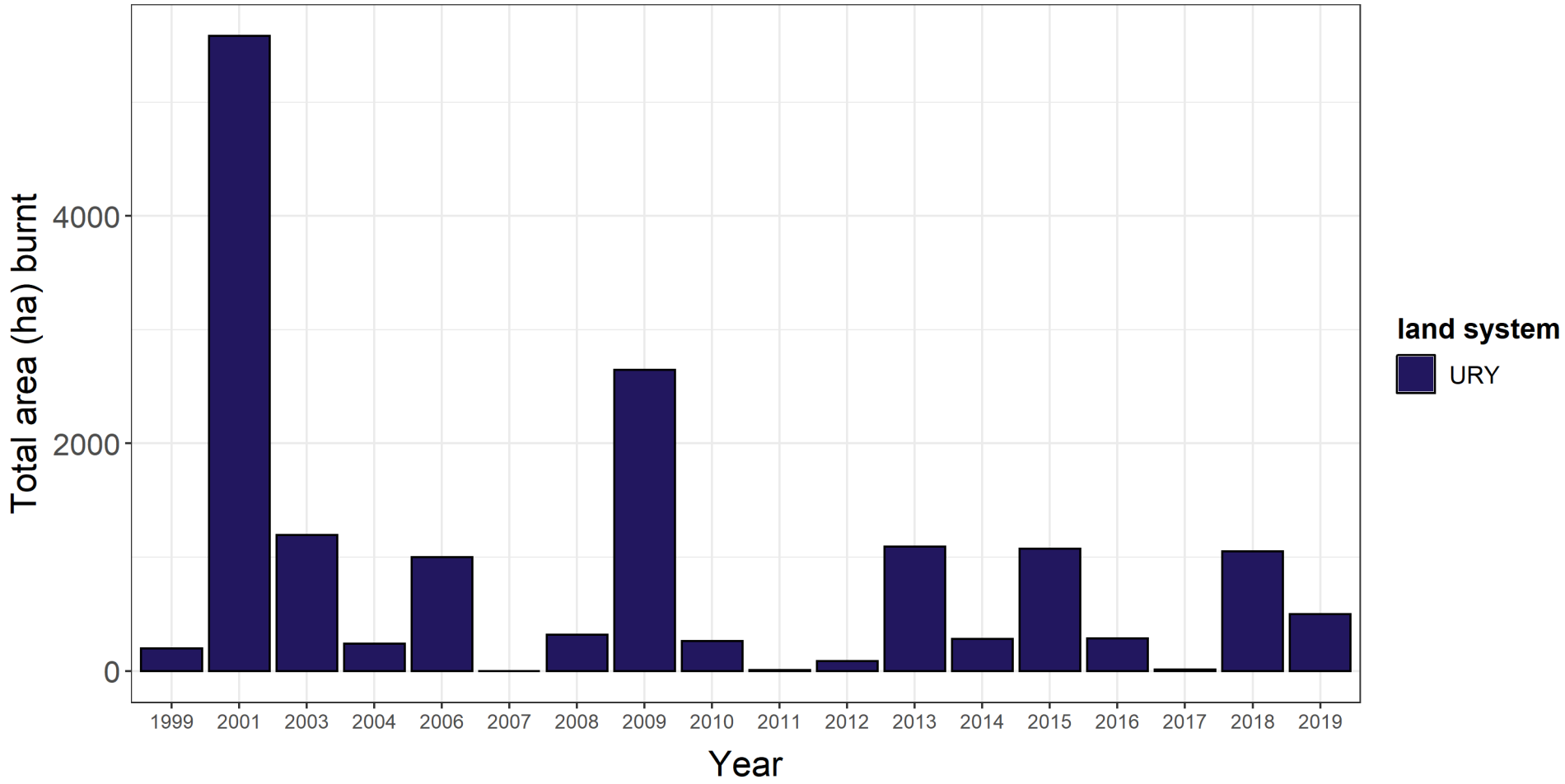

Figure 23 Total area (ha) burnt per year across the Urandy land system for each year of available fire mapping.

4 Data limitations

4.1 Spatial resolution

Landsat satellite imagery has a 30m pixel resolution for the reflectance bands which are used for extracting fire scars. Small fires less than 30m X 30m and detailed edging around larger fires are not able to be extracted at this resolution. Due to the uncertainty around the smaller fires any isolated area of mapped ‘fire’ less than 1 hectare is deleted from the final dataset.

4.2 Fire data attribution

At this current time, it is not possible to attribute the fire scar data with monthly date attribution for every month of the year. Fire scars are currently mapped using a difference image between two dates which are generally one year apart; occasionally they are mapped more frequently. Using this method, we are only capable of showing the change in the vegetation between those two dates and as such can only determine that the fire occurred at some point in that year interval.

4.3 Size class distribution of fire scars

In order to calculate metrics based on the size class distribution of fire scars it must first be possible to attribute the fire scars with a more accurate date. The fire scars represent an annual change in vegetation cover over an area. For example; if a fire starts in March and burns 50 ha before extinguishing then another fire starts in June and burns another 50 hectares right up to the boundary of the March fire an annual snapshot of that area would show one larger fire of 100 ha rather than two smaller 50 ha fires a few months apart in age. Calculating metrics based on size class distribution using the current fire scar data could overestimate the percentage of larger fires.

4.4 Missing annual fire scar data

Historical fire scar data for years 2000, 2002 and 2005 is not available; therefore, comparisons of annual changes in fire scar area cannot be made for the period 1999 – 2006. Where there are greater than annual gaps, the fire scars identified could have occurred at any time within the two year period between image dates. This impacts the fire metric analysis in that statistics such as average burnt area per year cannot be calculated across the entire time period.

The table below indicates the imagery dates for previous years fire mapping.

Table 9 Historical fire mapping image sources and dates over Red Hill pastoral lease

Source data	Image date	Mapping Year
NCAS	23/11/1999	1999
NCAS	16/02/2002	2001
NCAS	21/06/2004	2003
NCAS	16/02/2005	2004
NCAS	06/02/2007	2006
NCAS	04/10/2007	2007
NCAS	10/01/2009	2008
NCAS	14/02/2010	2009
USGS	23/12/2010	2010
USGS	12/02/2012	2011
USGS	02/03/2013	2012
USGS	25/02/2014	2013
USGS	16/03/2015	2014
USGS	29/12/2015	2015
USGS	31/12/2016	2016
USGS	18/12/2017	2017
USGS	06/01/2019	2018
USGS	24/12/2019	2019

4.5 Landsat 7 SLC-Off missing data stripes

During the period November 2011 to April 2013 the only available Landsat imagery was from Landsat 7 ETM+ and this imagery had missing data lines (‘stripes’) which affects the detection and attribution of fires scars. This results in some fires having ‘stripes’ of missing mapping which then affects the calculation of areas, fuel age and fire frequency.

Landsat images affected by the Scan Line Corrector (SLC) failure are missing approximately 22% of data. Generally, the most area lost is towards the edges of the scene with the middle of a scene unaffected. Figure 10 shows an example of the area of the Red Hill LMA affected by the SLC failure in 2012. The white stripes in the image represent missing data.

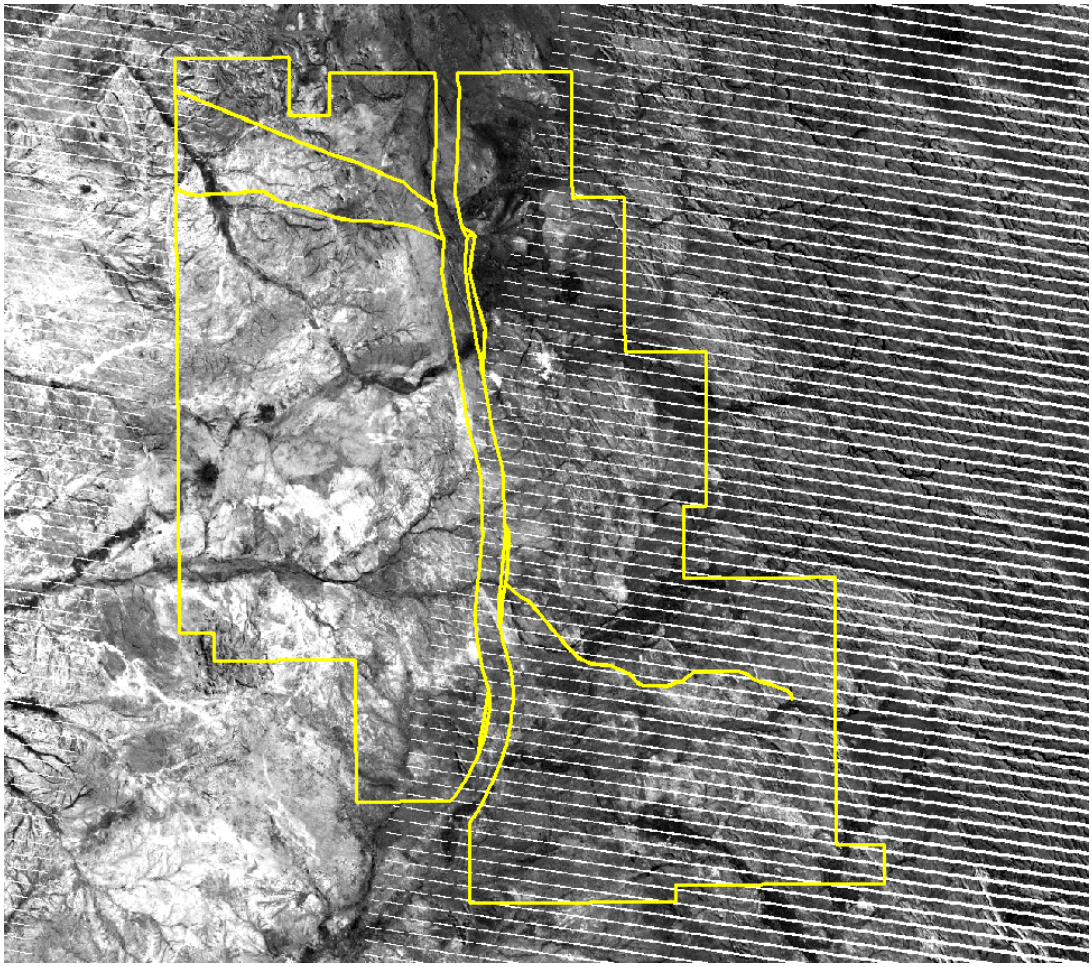

Figure 24 Location of missing data across the Red Hill LMA for Landsat image date 02/03/2012.

Landsat 7 images affected by the SLC failure were used for the fire mapping in years 2012 and 2013. Within the Red Hill LMA approximately 5.6% of data is missing for these years.

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van Vreeswyk, A. M., Leighton, K. A., Payne, A. L., and Hennig, P., (2004). An inventory and condition survey of the Pilbara region, Western Australia, Department of Agriculture and Food, Western Australia. Technical Bulletin 92, 424p.

Data delivery

Datum and projection: GDA 94 MGA50

Date delivered: 25/8/2020

Contact: Katherine Zdunic/Jane Chapman, Remote Sensing Science, Department of Biodiversity, Conservation and Attractions

17 Dick Perry Avenue, Kensington. Katherine.Zdunic@DBCA.wa.gov.au, Jane.Chapman@dbca.wa.gov.au

Dataset Delivered	**Format**	**Description**
RedHill_Fire_1998_2019_10km_buff	ESRI shapefile	Fire scar mapping for Yarraloola LMA and surrounding area within a 10 km buffer for the time period 1999 – 2019 for all available years
RedHill_2019_Fire_stats_report	PDF	This report document
RedHill_graphs	JPEG	The graphs contained in the report as JPEGs derived from the raw data
redhill_total_area_burnt_years_stats_2019	Excel csv	Raw data

Appendix 3: Vegetation cover change assessment on Yarraloola and Red Hill

Vegetation cover change assessment on Yarraloola and Red Hill - Remote Sensing monitoring program report 2019

Ricky van Dongen

Vegetation cover change monitoring for Rio Tinto

July 2020

GOVERNMENT OF WESTERN AUSTRALIA

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November 2020

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This document is available in alternative formats on request.

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Contents

Figures

Tables

Summary

The aim of this project is to identify changes to current vegetation cover compared with 1988-2014 levels across Yarraloola and Red Hill stations using Landsat satellite data. Results indicate that across Yarraloola and Red Hill 269 km sq (14.1%) experienced an increase above baseline levels (1988 – 2014) and 319 km sq (17.9%) experienced a decrease below baseline levels.

Examination of time series graphs within areas of significant change and field investigations are required to determine the cause of vegetation cover change from baseline levels and whether the change represents an improvement or reduction in condition. A significant reduction in vegetation cover, below the 1988 to 2014 mean, was observed at sites YL-15 and YL-16 (see Figure 4).

1 Methodology

1.1 Landsat imagery

Imagery from the Landsat satellite series is used in this analysis (https://landsat.usgs.gov/). The Landsat satellites began capturing data in the 1970's with regular captures from 1988. Imagery is collected at 30 m pixel size across 6 spectral bands. Landsat data are fundamental to monitoring long term vegetation change globally (Hansen et al., 2013). The Landsat archive has recently been made available to download free of charge from the United States Geological Survey (USGS). In this project Landsat imagery from 1988 to 2019 is being used to map and monitor changes to vegetation cover.

All Landsat imagery covering Yarraloola and Red Hill (scene 114/075, Figure 1) available for download from the USGS from 1988 to the beginning of 2020, with less than 30% cloud cover, was acquired. This ensured complete and comprehensive coverage of the stations. The imagery was corrected for variable sun angle and distance using the CSIRO software "Sun_Correct" (Wu and Danaher, 2001) to enable comparisons through time.

Figure 1 Landsat image extent for scene location 114/075.

1.2 Vegetation cover index

The Landsat imagery was converted from digital counts of reflectance to a vegetation cover index. The index is an estimate of vegetation cover generated from field data supplied by Rio Tinto. The index was created using field measures assessing total cover (%) from 29 plots within Red Hill and Yarraloola. The field measures were regressed against their associated i35 index ((Landsat red band + Landsat short wave infrared band 1)/2).

The i35 index was developed in the south west of Western Australia (Caccetta et al., 2000) and has been applied across the continent to monitor change in woody vegetation cover (Lehmann et al., 2013). Along with vegetation cover the reflectance of soil or rock will heavily influence the index value. As a result areas of low cover can have a range of index values which may appear as outliers in a regression. Cook's distance was used to identify outliers which are particularly influential on the regression of total cover against the i35 index. Cook's distance plots the residual (distance from a model) with leverage (the points influence on the model) (Crawley, 2007). Using this method two field sites were identified as outliers and were removed from the analysis (Figure 2).

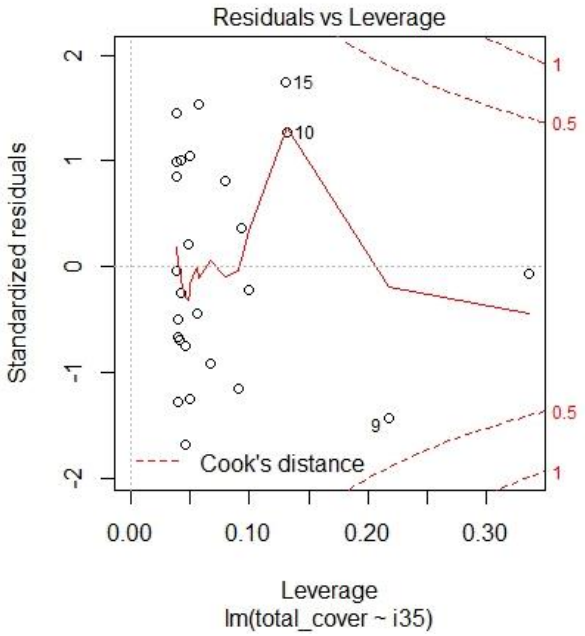


Figure 2 Cook's distance assessment of points in the i35 to vegetation cover regression (point 9 is RH-x, and point 15 is YESG01).

The regression of total cover against the i35 index is shown in Figure 3. A moderate relationship ($r^2 = 0.469$) was recorded.

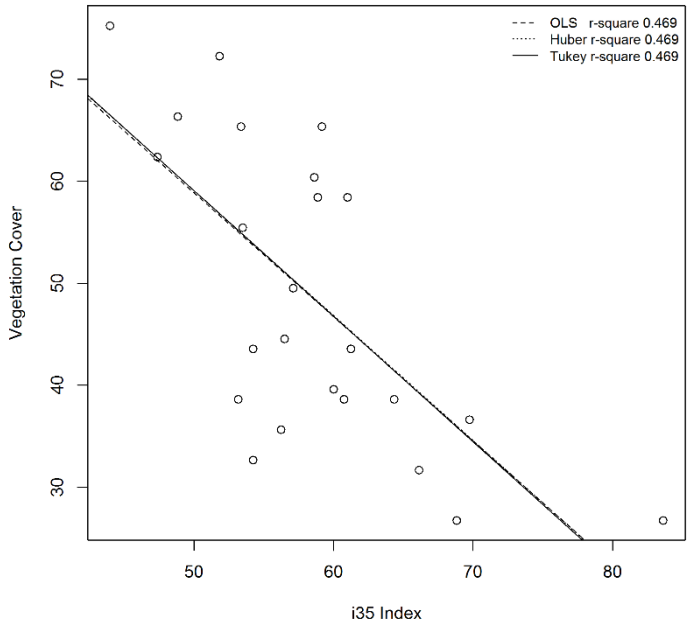


Figure 3 Regression of field measures of vegetation cover against the i35 index.

The ordinary least squared regression line followed the equation y = -1.2154x + 119.64. This equation was then applied to the i35 index to create the vegetation cover index images which are summarized in the time series plots (presented in Sections 2.3 and 2.4). Note that areas where the i35 index is greater than the maximum value used in the training data will return a cover index value less than 0.

1.3 Cover change images and graphs

The methodology used to examine vegetation cover change is adapted from Zhu et al., (2012) and Gove et al., (2013). Zhu et al., (2012) used all available Landsat imagery to detect forest disturbance at high temporal frequency, while Gove et al., (2013) demonstrated the utility of using control charts as a means of detecting shifts in time series data. The analysis technique involved plotting vegetation cover values from annual Landsat imagery and applying the Cumulative Sum (CUSUM) test (Gove et al., 2013).

The change image represents change in perennial cover as the satellite imagery used is dry season imagery. One Landsat image per year from 1988 to 2019 from the end of the dry season (around November) was selected. This imagery was then put into a “stack” and the CUSUM formula applied. The use of dry season imagery means that changes in ephemeral plant cover are excluded.

To apply the CUSUM formula, baseline periods need to be identified. The 1988 to 2014 period was used as a baseline for Yarraloola and Red Hill. Changes in vegetation cover above or below the mean of the baseline period can then be

detected. This technique was utilised to produce a spatial representation of significant vegetation cover change which was classified into 5 classes (Table 1). The cause of change can then be attributed by examining time series plots and field validation.

The vegetation change classes listed in Table 1 are consistent with those used in previous Department of Biodiversity, Conservation and Attractions (DBCA) projects (van Dongen and Huntley, 2016). However, they are subjective and may be adjusted if fieldwork demonstrates that they are insensitive or overly sensitive to change.

Table 1 Thresholds used to identify areas of change.

	Cusum threshold
Large increase	> 50
Moderate increase	> 25 and < = 50
Stable	> -25 and <= 25
Moderate decrease	> -50 and < = -25
Large decrease	<-50

Areas of significant change in vegetation cover from the baseline identified in the vegetation cover change map were identified further using check points. At each check point satellite derived vegetation cover estimates for the period 1988 to 2020 were graphed. The mean baseline vegetation cover level for each point and standard deviations are also shown. This allows recent changes in vegetation cover to be examined in relation to the range of values observed during the baseline period (1988 – 2014).

2 Results

Examples of how the resultant graphs and images can be interrogated are shown in Figures 4 to 6. Figure 4 displays aerial photography from August 2007 (Figure 4a) and July 2014 (Figure 4b) (© Landgate (2018)), a change in vegetation cover is evident in these photographs. This area is shown in the vegetation cover change map (Figure 4c) as having regions of moderate and large decreases in vegetation cover.

The time series graph shows the change in vegetation cover at this point over the 1988 to 2020 time period. The graph indicates that cover levels are currently low and outside the normal range observed during the baseline period. The imagery indicates that this significant change occurred around June 2017.

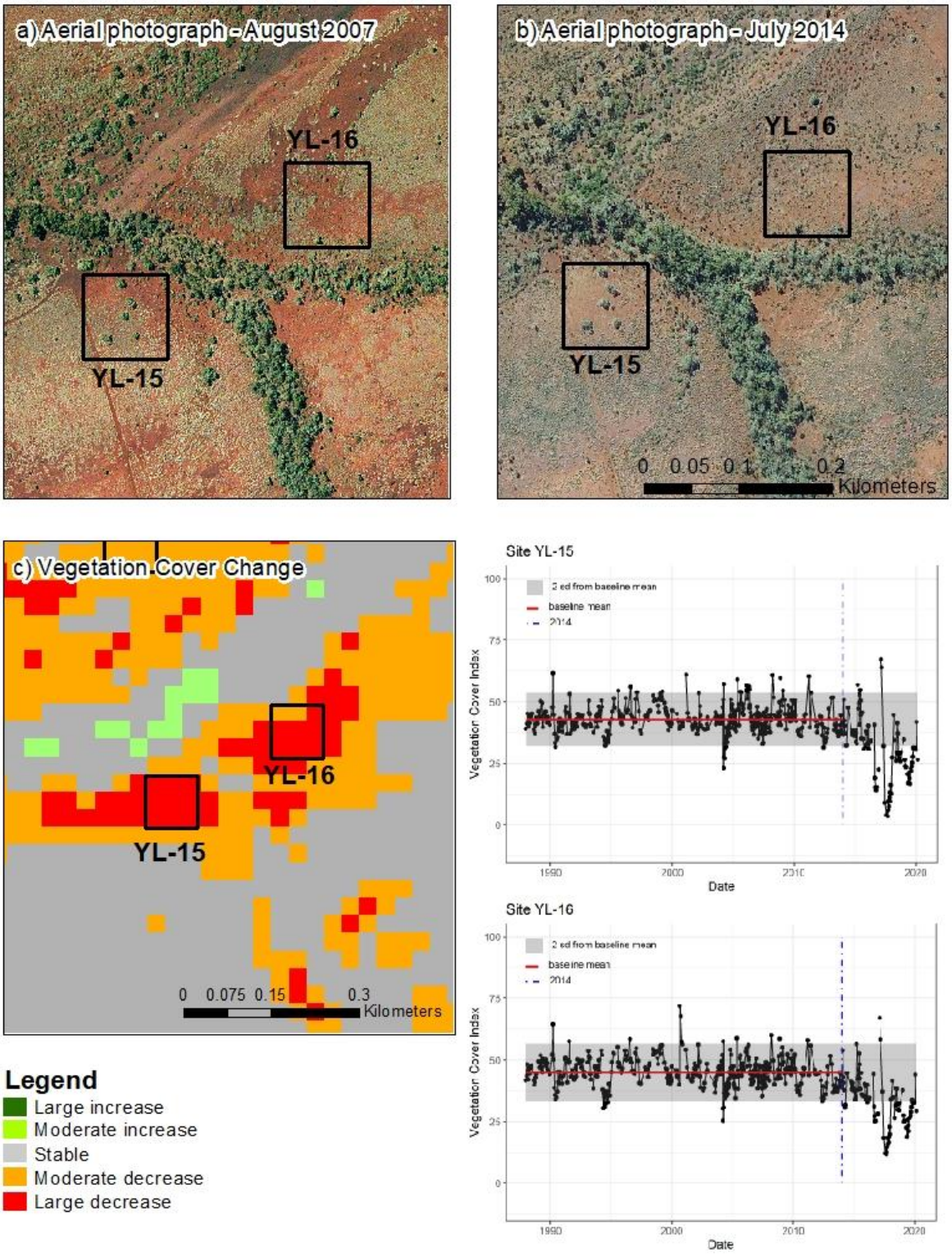


Figure 4 An example of an area of vegetation cover decline in Yarraloola. This includes aerial photography from August 2007 and July 2014 (© Landgate (2018)), a vegetation cover change image and a time series graph. The dashed blue vertical line is at 1/1/2014, the baseline mean is a solid red line and the range within 2 standard deviations of the baseline mean is shaded in grey.

Figure 5 includes aerial photography from November 2005 (Figure 5a) and August 2012 (Figure 5b) (© Landgate (2018)), these photographs provide an example of changes in vegetation cover at the site . This area is shown in the vegetation cover change map (Figure 5c) as having a large increase in vegetation cover. The time series graph shows the change in vegetation cover at this point over the 1988 to 2020 time period. The large increase in cover recorded at this site appears due to the current long period since fire. In comparison there are three fires in the baseline period.

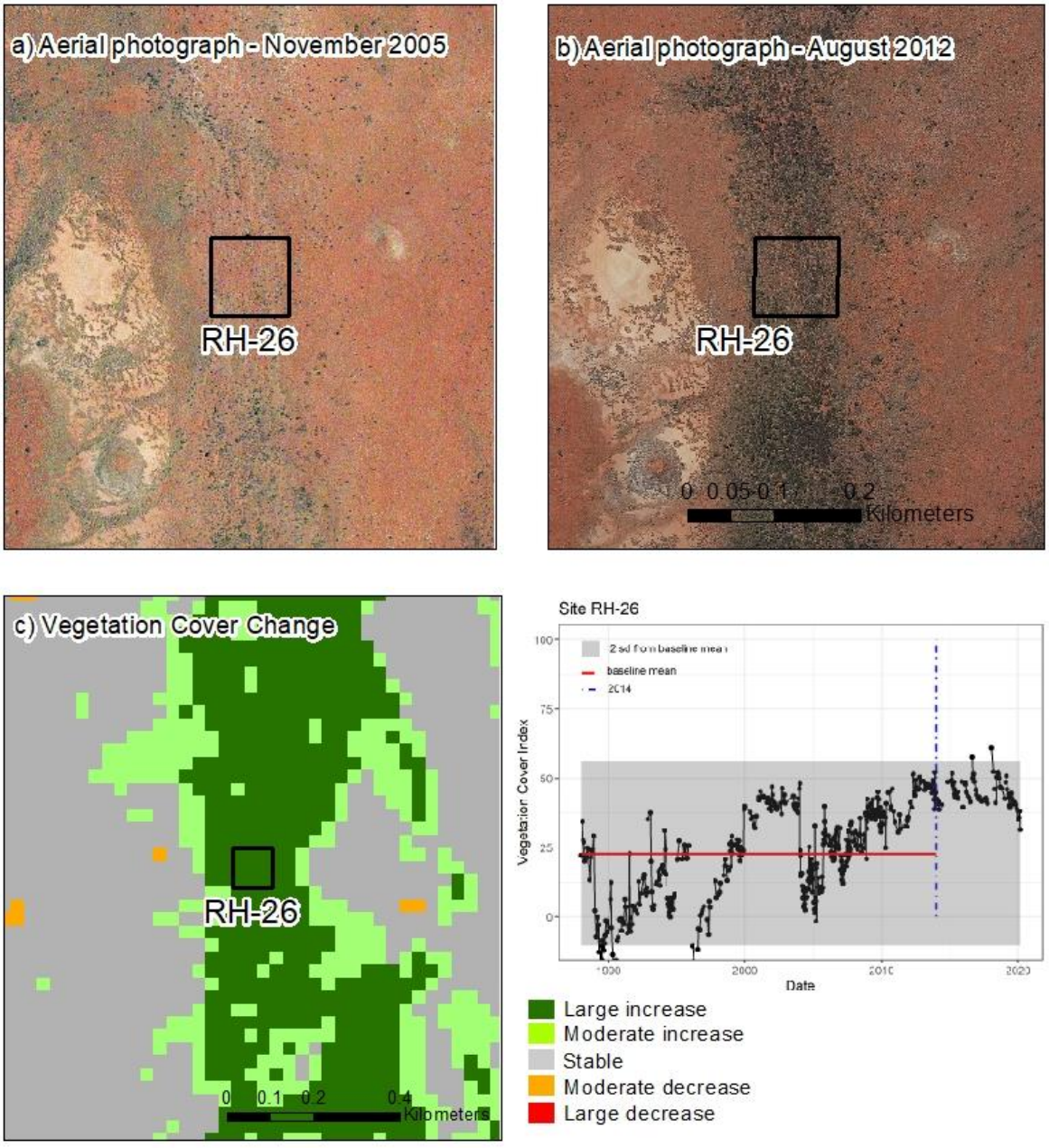


Figure 5 An example of an area of vegetation cover increase in Red Hill. This includes aerial photography from November 2005 and August 2012 (© Landgate (2018)), a vegetation cover change image and a time series graph. The dashed blue vertical line is at 1/1/2014, the baseline mean is a solid red line and the range within 2 standard deviations of the baseline mean is shaded in grey.

Figure 6 includes an area where the vegetation cover in the 2015 to 2018 period is consistent with the mean from the 1988 to 2014 time period. It is evident from the time series graph that cover has large, regular annual fluctuations. This seasonal variance may explain the difference in appearance of the 2007 and 2015 aerial photographs (© Landgate (2018)).

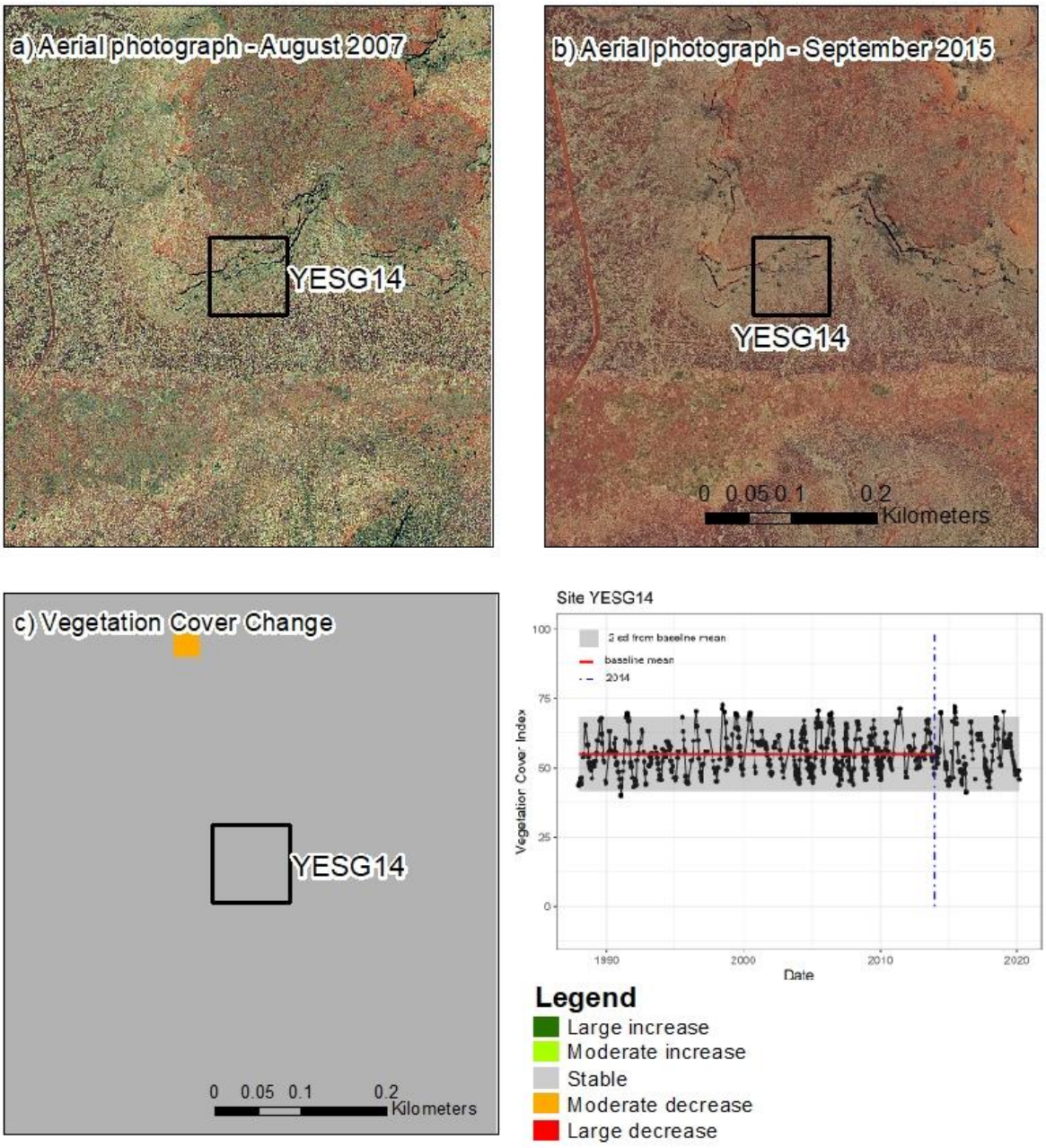


Figure 6 An example of an area where vegetation cover has not changed from the pre 2014 mean in Yarraloola. This includes aerial photography from 2007 and 2015 (© Landgate (2018)), a vegetation cover change image and time series graphs. The dashed blue vertical line is at 1/1/2014, the baseline mean is a solid red line and the range within 2 standard deviations of the baseline mean is shaded in grey.

2.1 Vegetation cover change maps

The areas where vegetation cover change has changed to 2019 compared to baseline levels, and the location of check points, are displayed in figure 7 for both Red Hill and Yarraloola.

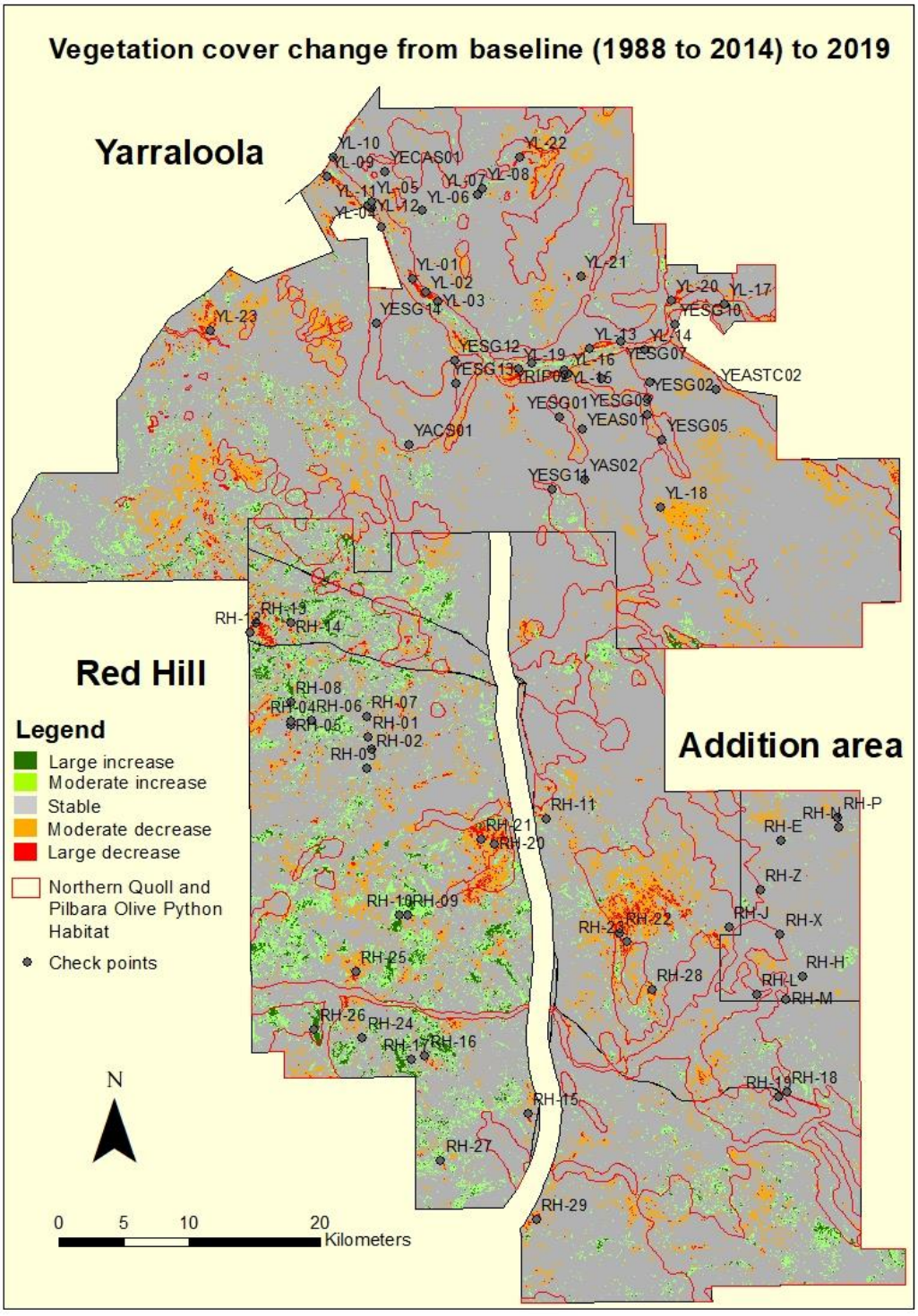


Figure 7 A map of vegetation cover change from the 1988 to 2014 baseline across Yarraloola and Red Hill. The location of check points is also shown.

The area of change within each property and change class displayed in Figure 7 can be calculated. Area and percentage figures are shown in Table 2.

Table 2 The percentage area of vegetation cover change from baseline values from Yarraloola and Red Hill.

	Red Hill		Yarraloola	
Class	sq km	Area %	sq km	Area %
Large increase	37.05	1.82	5.46	0.35
Moderate increase	171.48	8.41	54.78	3.52
Stable	1660.84	81.49	1347.12	86.51
Moderate decrease	145.60	7.14	133.76	8.59
Large decrease	23.14	1.14	16.07	1.03
Water	0.00	0.00	0.01	0.00

The area of change within northern quoll (NQ) and pilbara olive python (POP) habitat on each property are shown in Table 3.

Table 3 The percentage area of vegetation cover change from baseline values from northern quoll and pilbara olive python habitat on Yarraloola and Red Hill.

	Red Hill – NQ and POP habitat		Yarraloola – NQ and POP habitat	
Class	sq km	Area %	sq km	Area %
Large increase	3.96	0.59	1.47	0.23
Moderate increase	32.34	4.79	13.25	2.07
Stable	570.98	84.57	555.53	86.68
Moderate decrease	57.78	8.56	63.87	9.97
Large decrease	10.07	1.49	6.78	1.06
Water	0.00	0.00	0.01	0.00

2.2 Time series graphs at check points

Time series graphs of all check points are shown below. A summary of the number of check points added to each property in each cover change class is shown in Table 4.

Table 4 The number of check points in each change class and property.

	Red Hill		Yarraloola	
Class	Number of check points	Number of check points per sq km	Number of check points	Number of check points per sq km
Large increase	6	0.16	5	0.92
Moderate increase	4	0.02	2	0.04
Stable	15	0.01	17	0.01
Moderate decrease	0	0.00	2	0.01
Large decrease	13	0.56	16	1.00
Grand Total	38	0.02	42	0.03

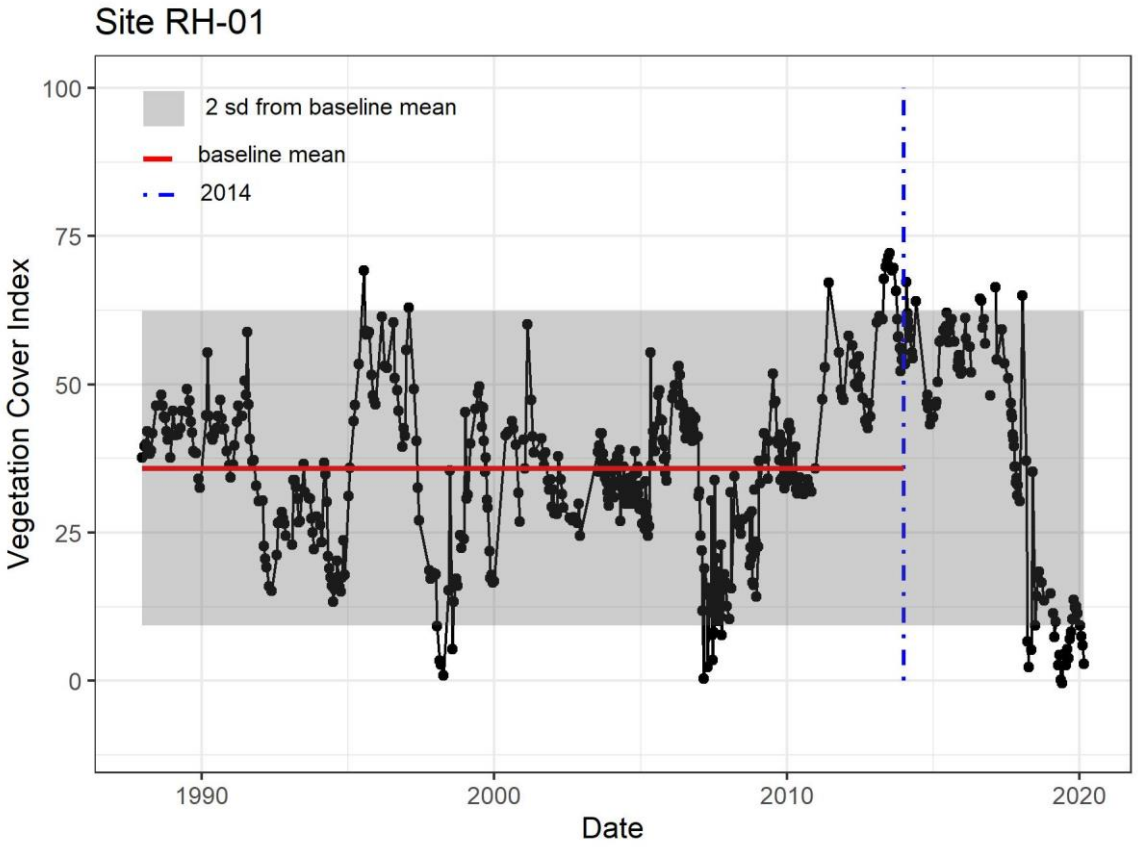
A summary of the number of check points, within northern quoll (NQ) and pilbara olive python (POP) habitat, on each property in each cover change class is shown in Table 5.

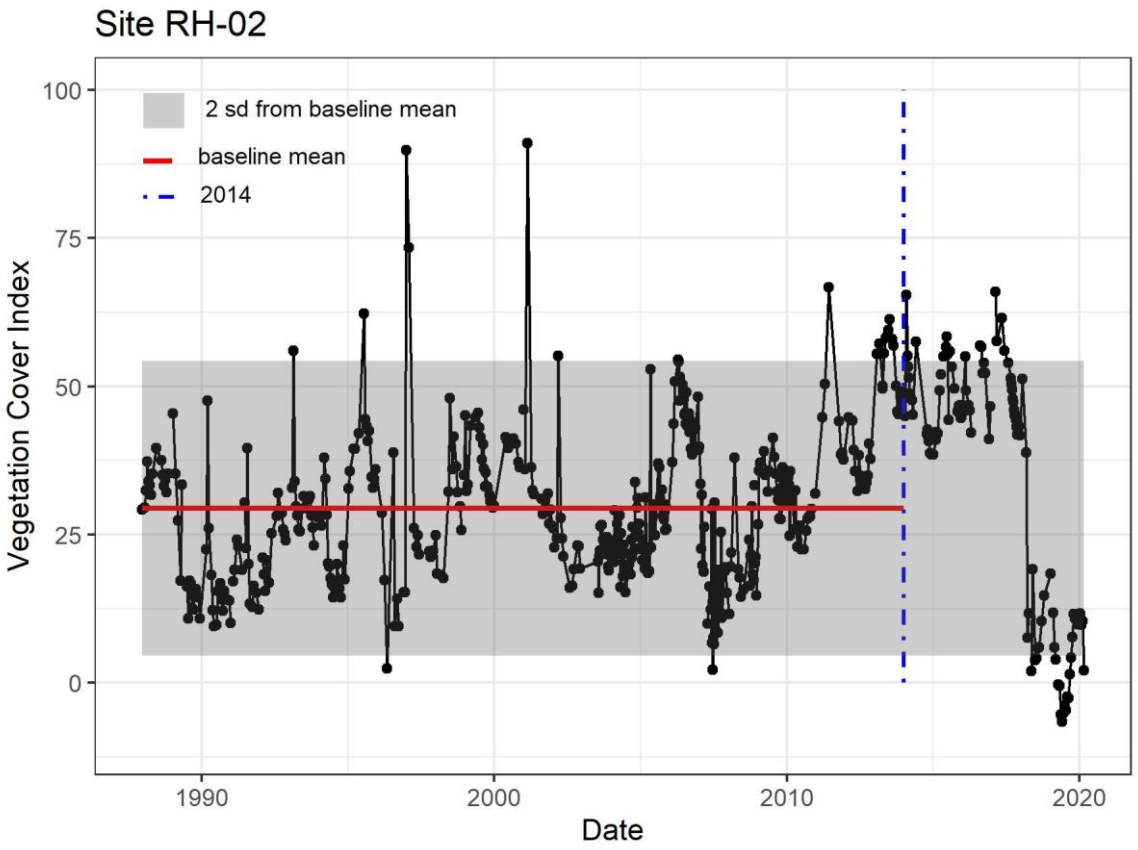
Table 5 The number of check points in each change class and property within northern quoll and pilbara olive python habitat.

	Red Hill – NQ and POP habitat		Yarraloola – NQ and POP habitat	
Class	Number of check points	Number of check points per sq km	Number of check points	Number of check points per sq km
Large increase	0	0.00	2	1.36
Moderate increase	0	0.00	2	0.15
Stable	10	0.02	13	0.02
Moderate decrease	0	0.00	2	0.03
Large decrease	3	0.30	8	1.18
Grand Total	13	0.02	27	0.04

2.3 Time series plots from Red Hill

The time series vegetation cover graphs for Red Hill are shown below. The red line is the baseline (1988 to 2014) mean, the grey area shows the range within two standard deviations from this mean and the blue dashed line indicates the end of the baseline period (2014).

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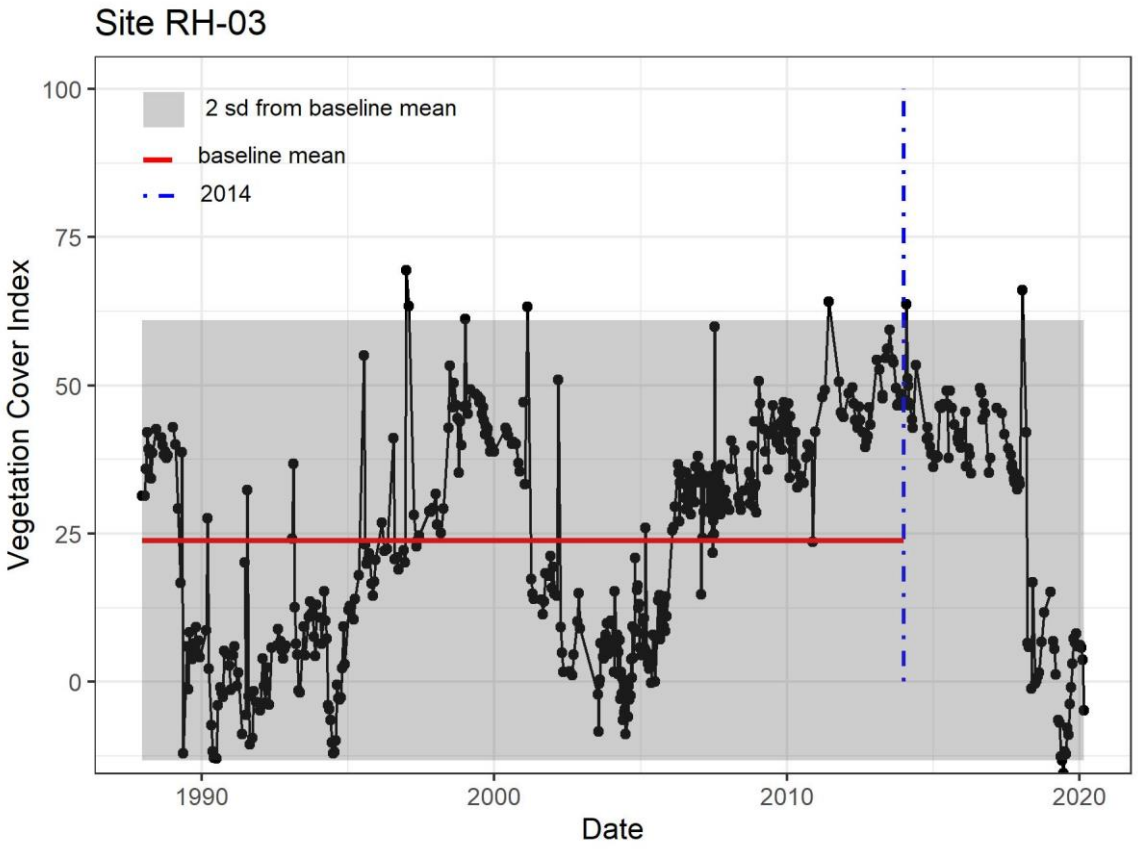
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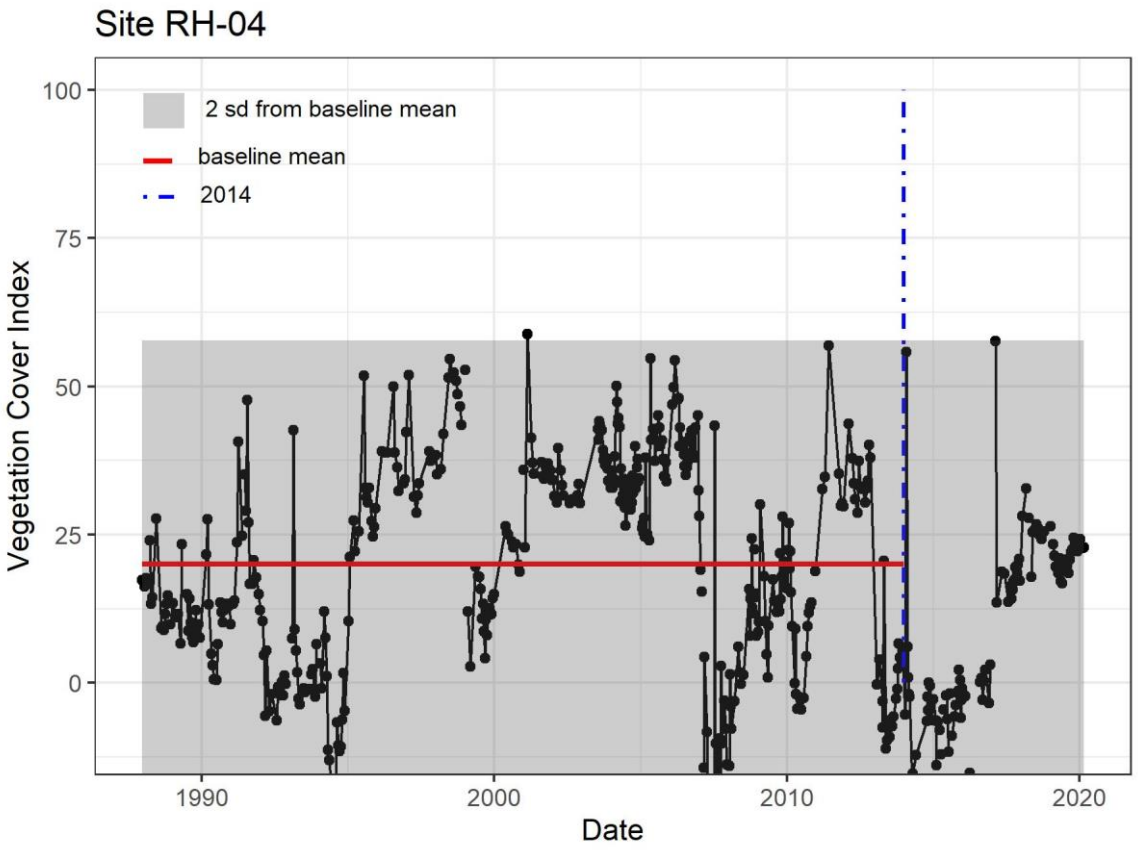
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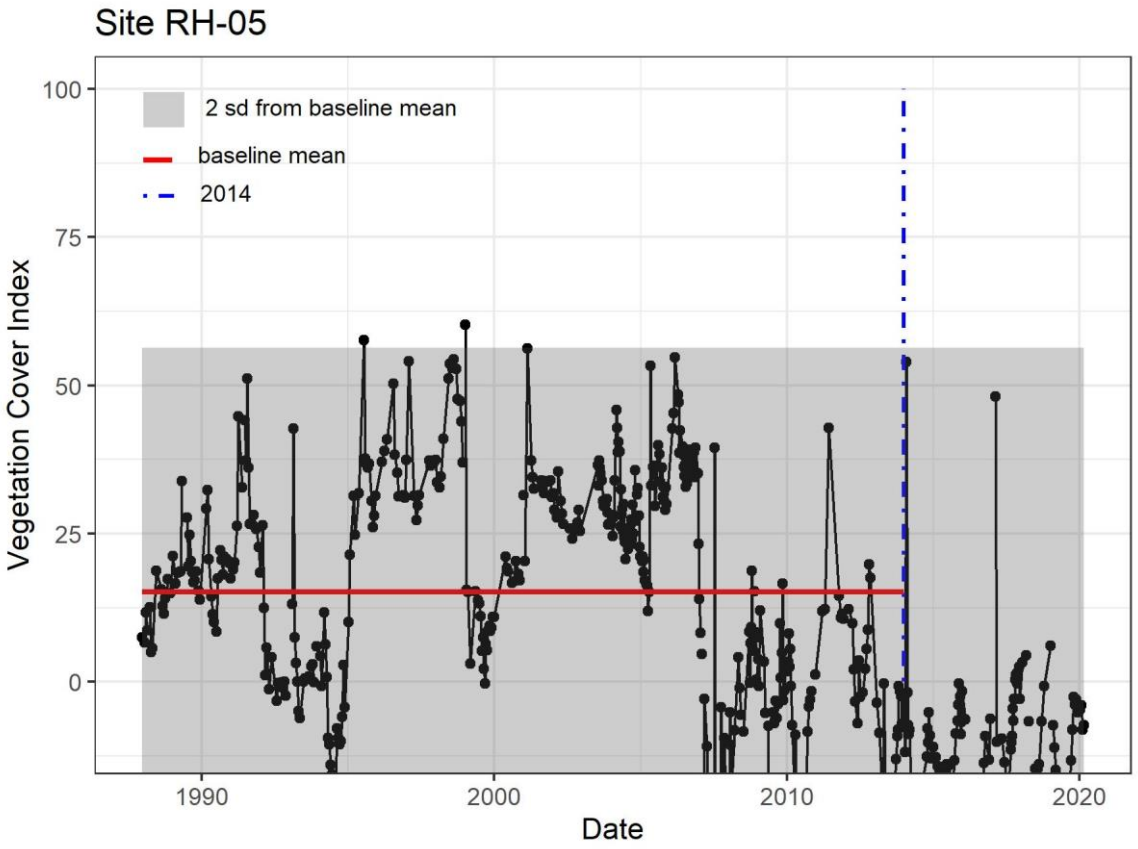
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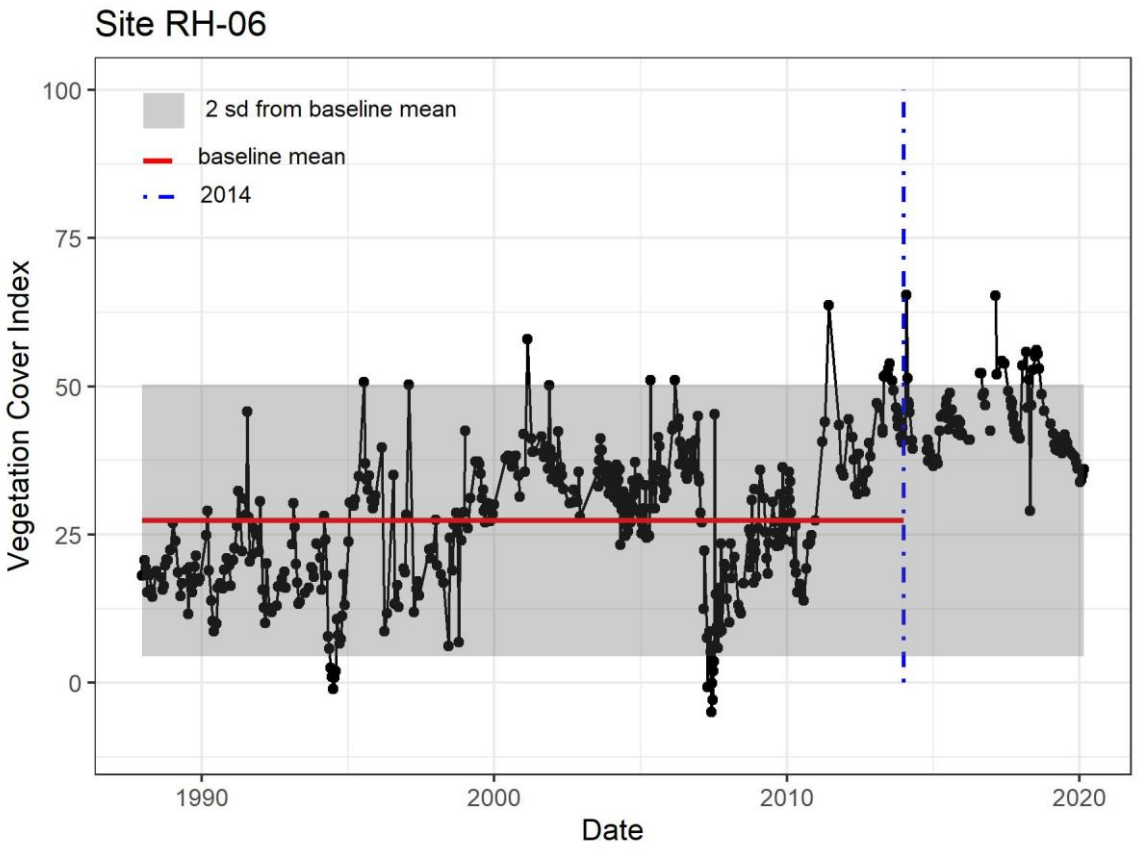
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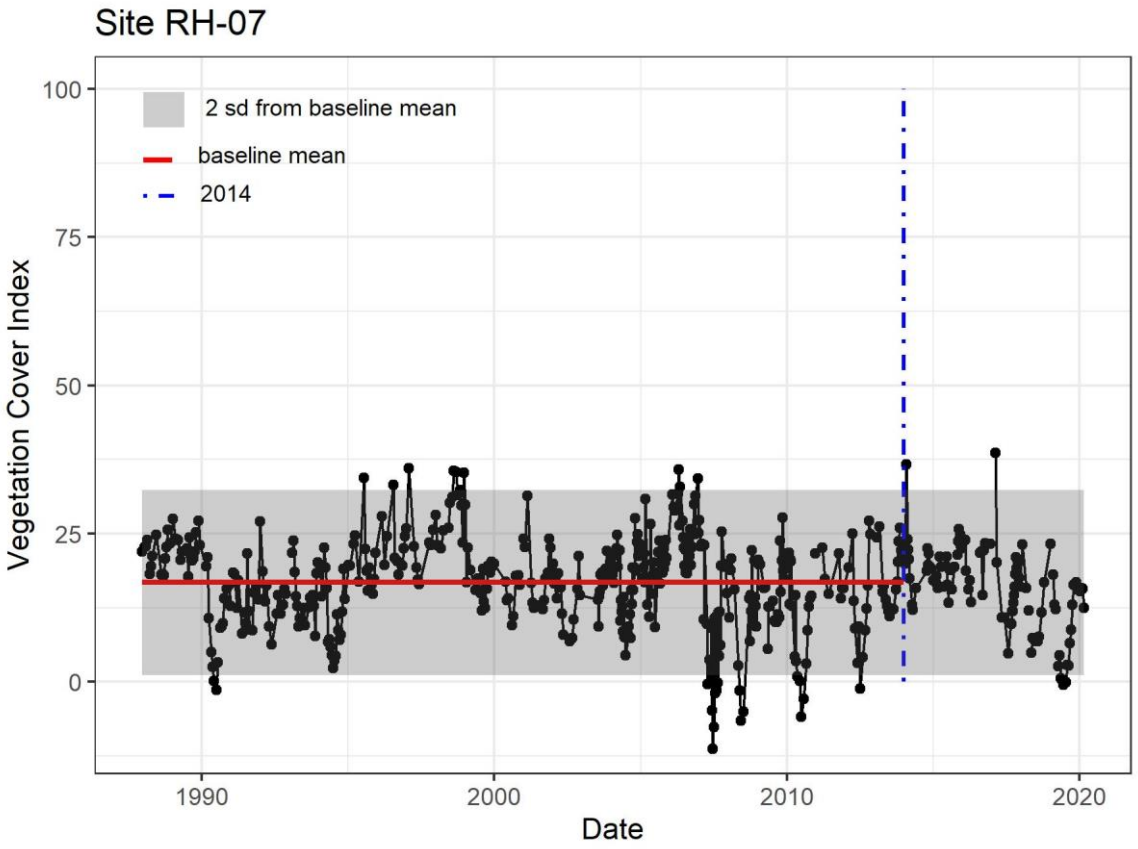
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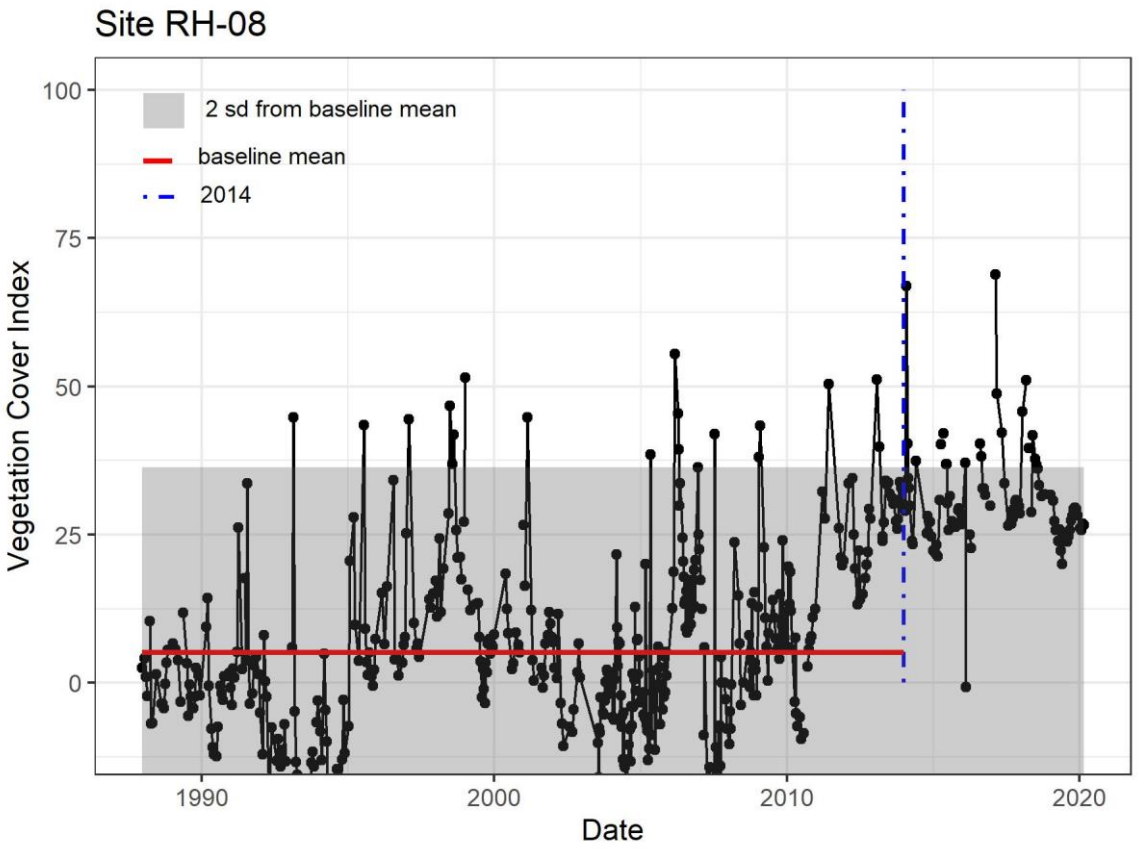
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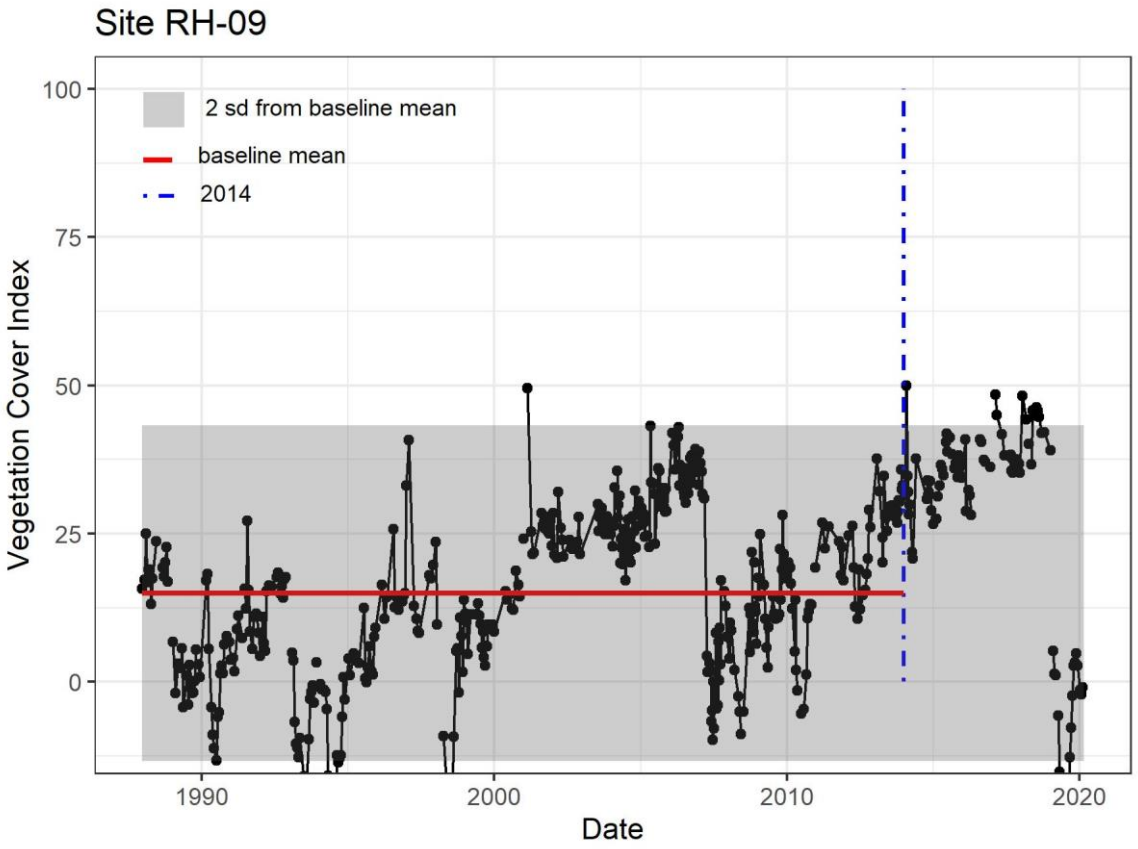
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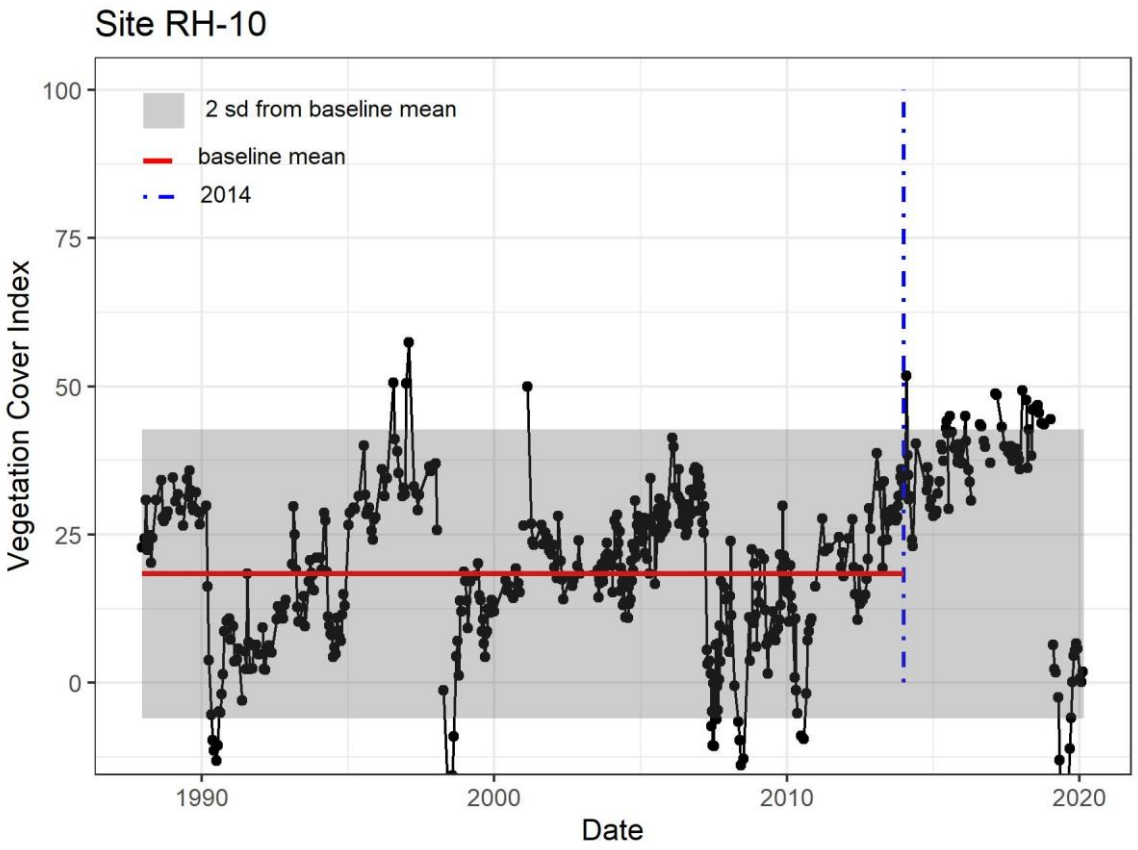
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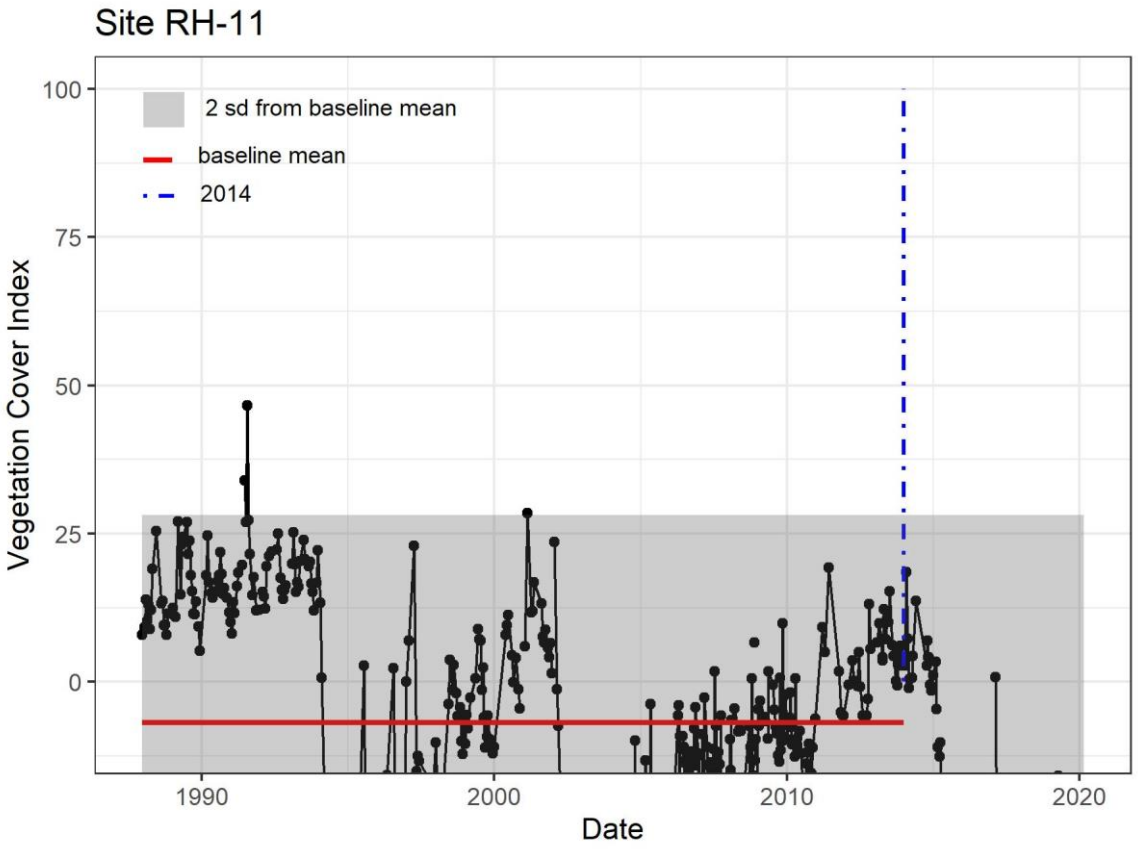
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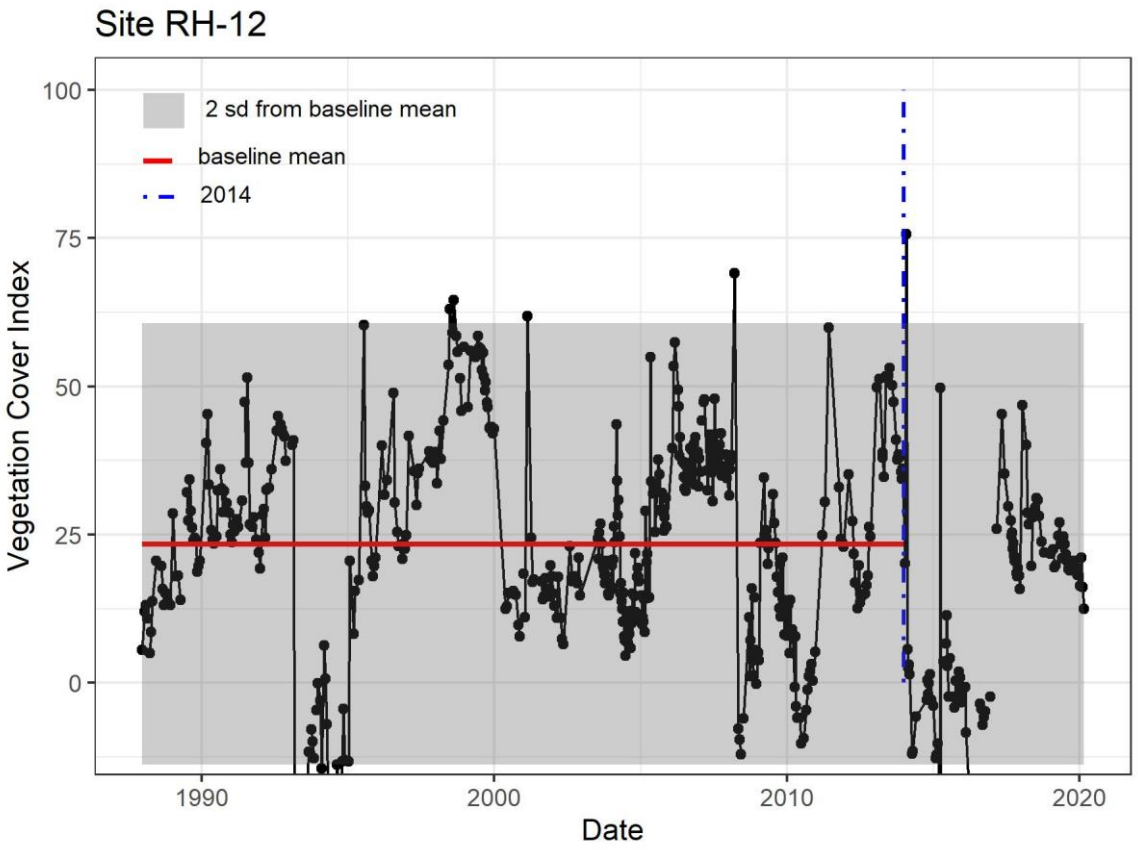
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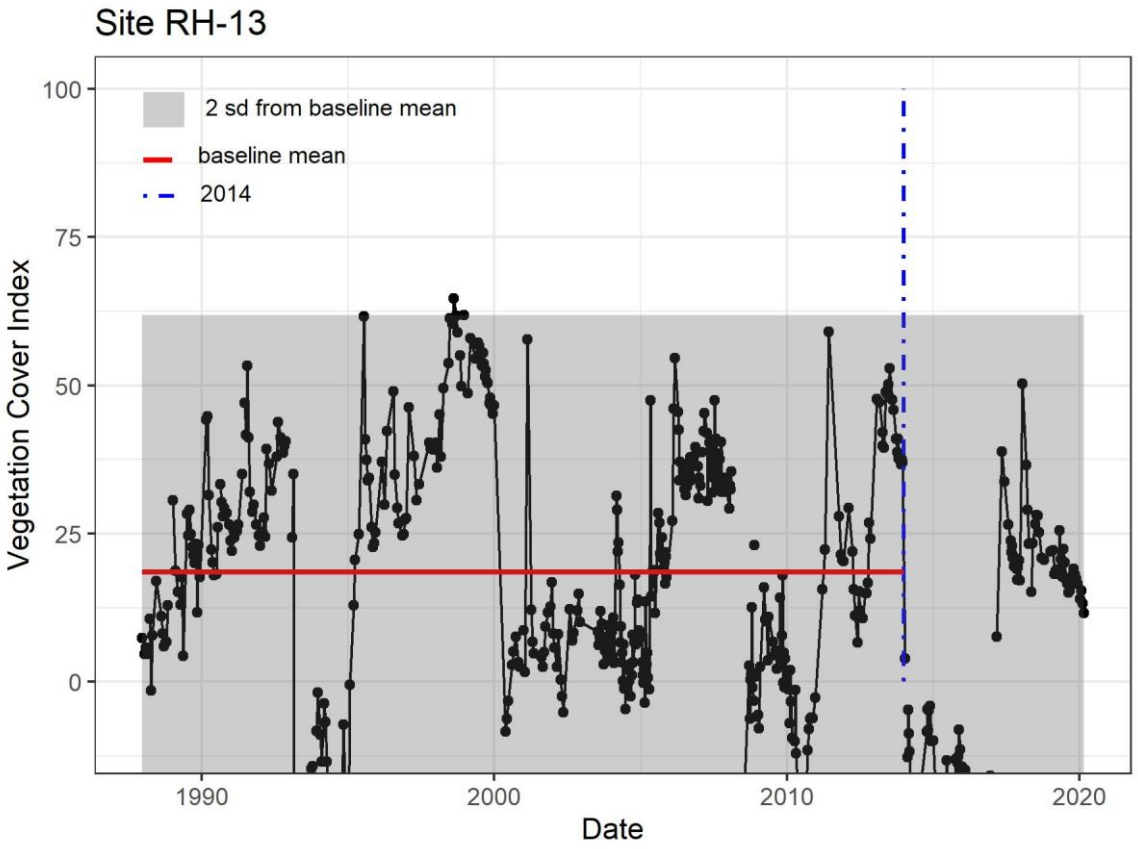
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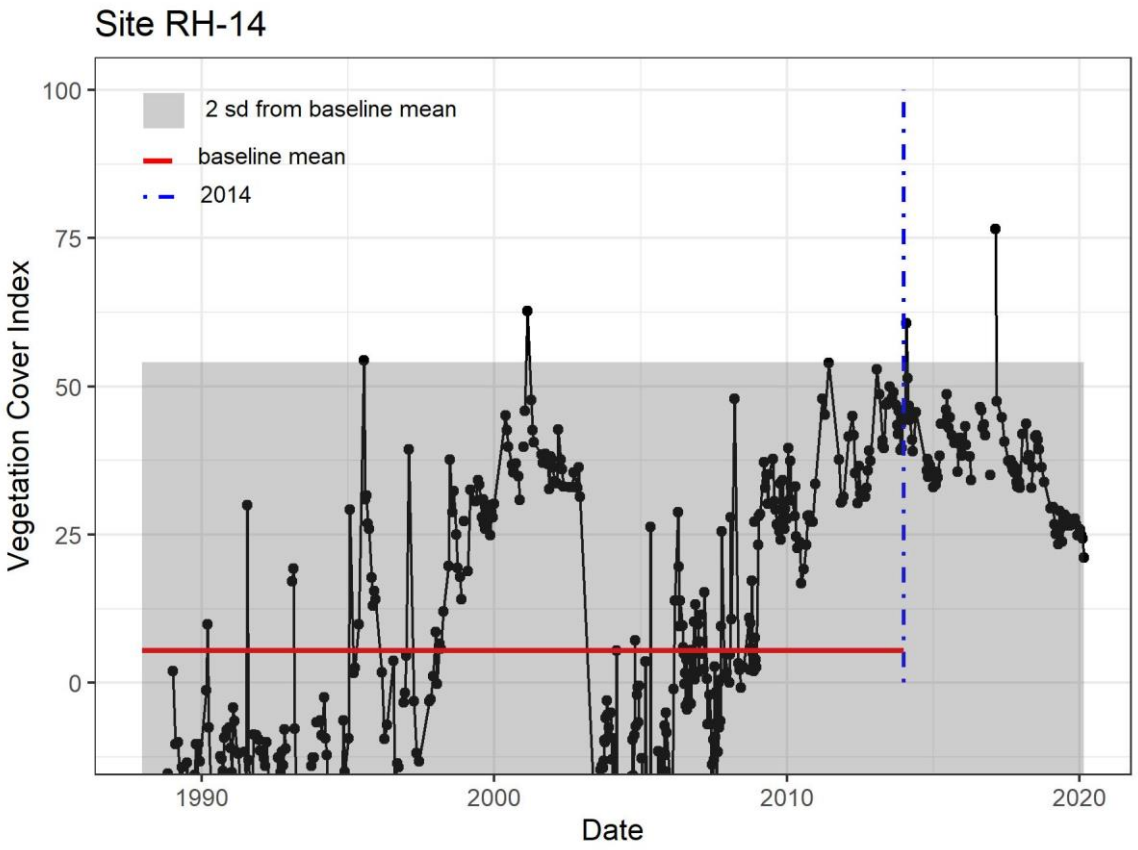
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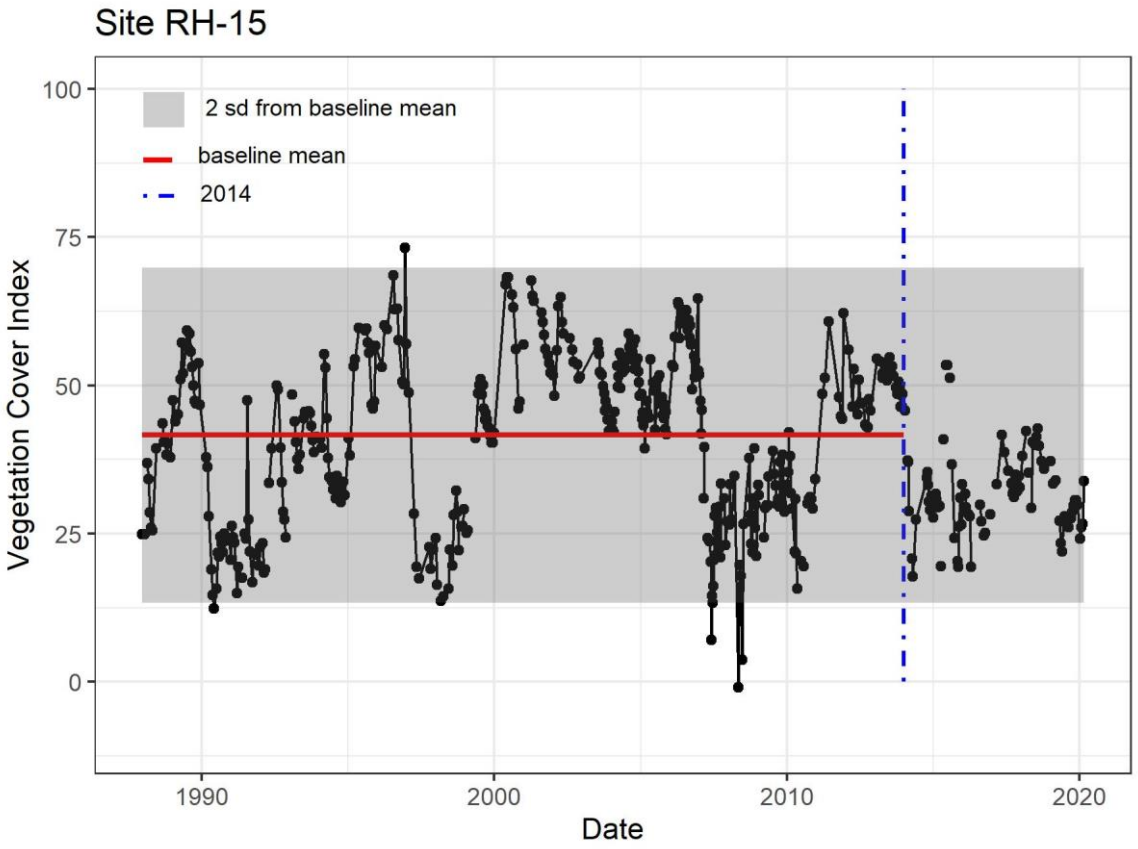
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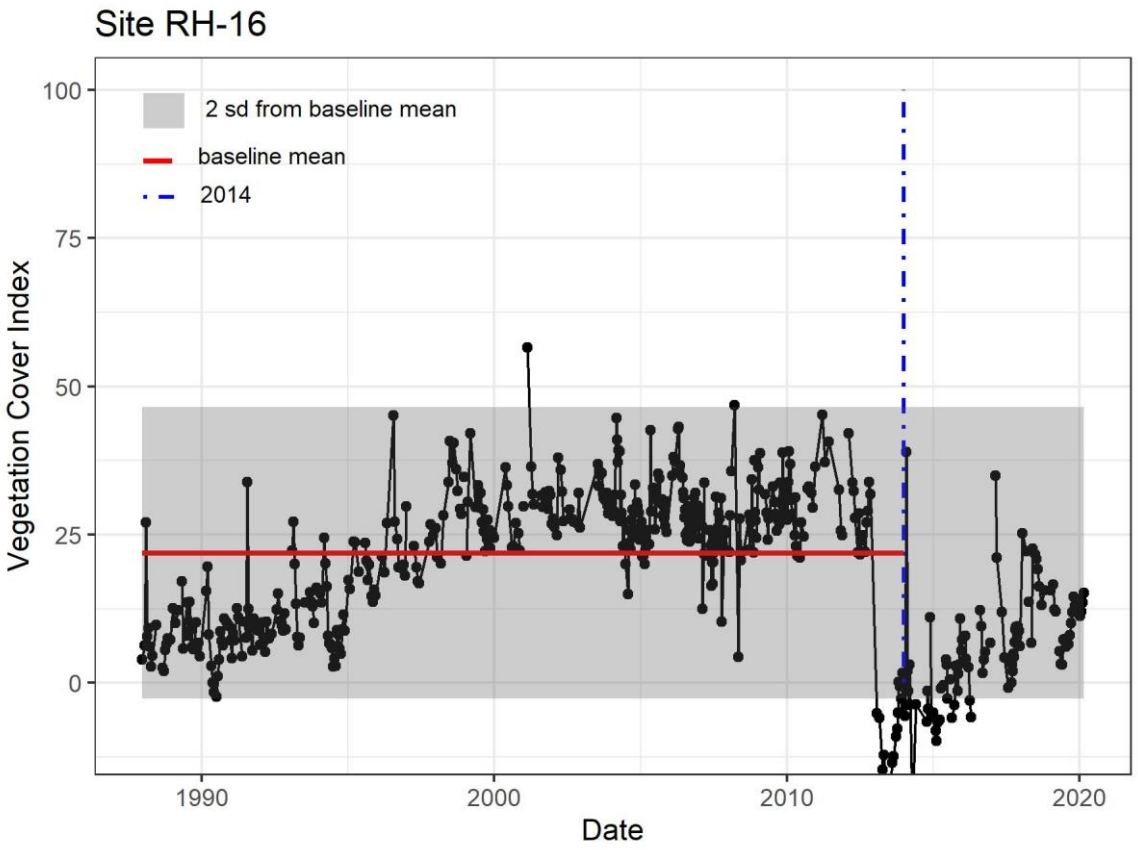
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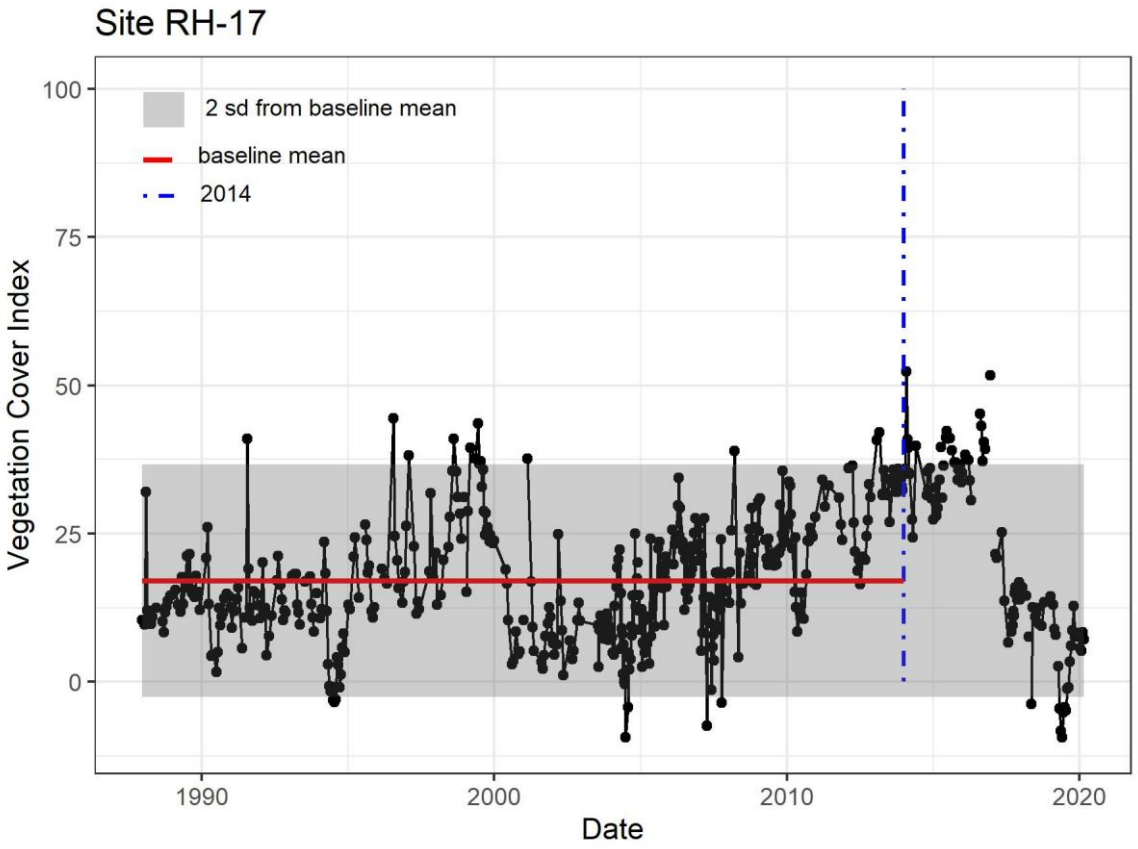
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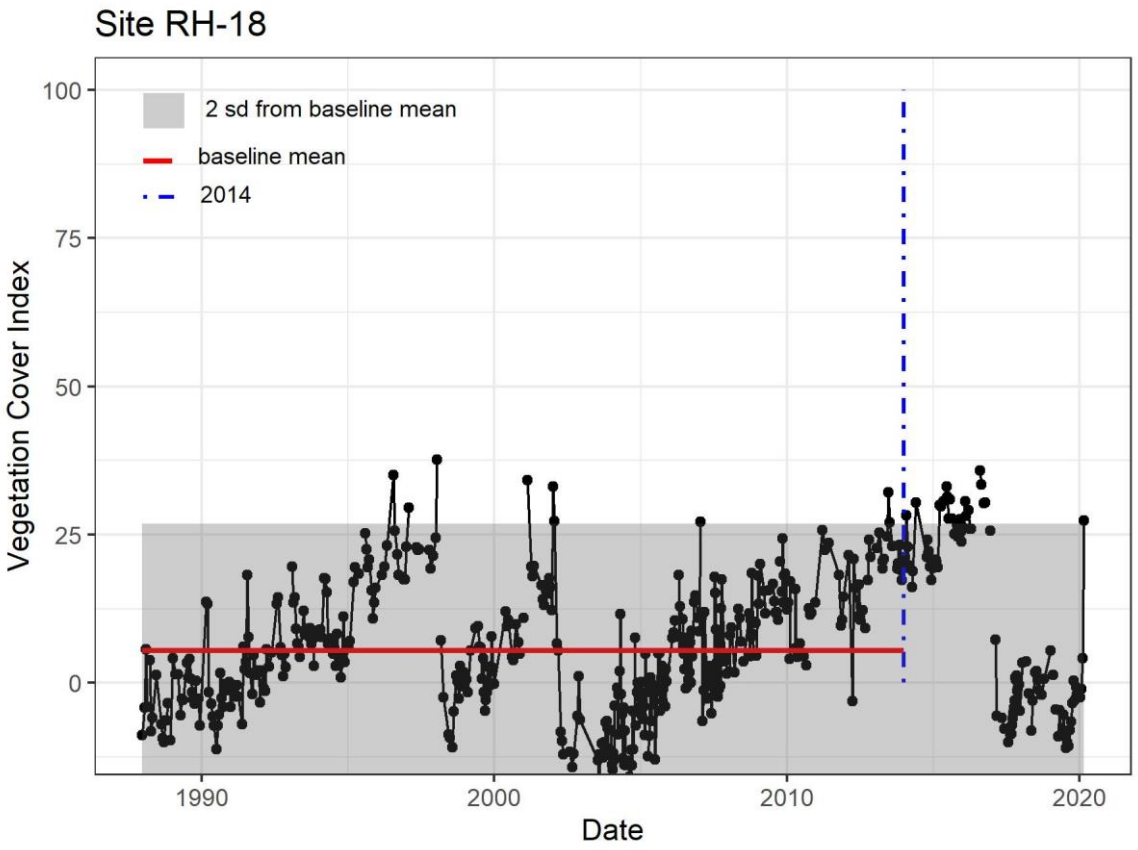
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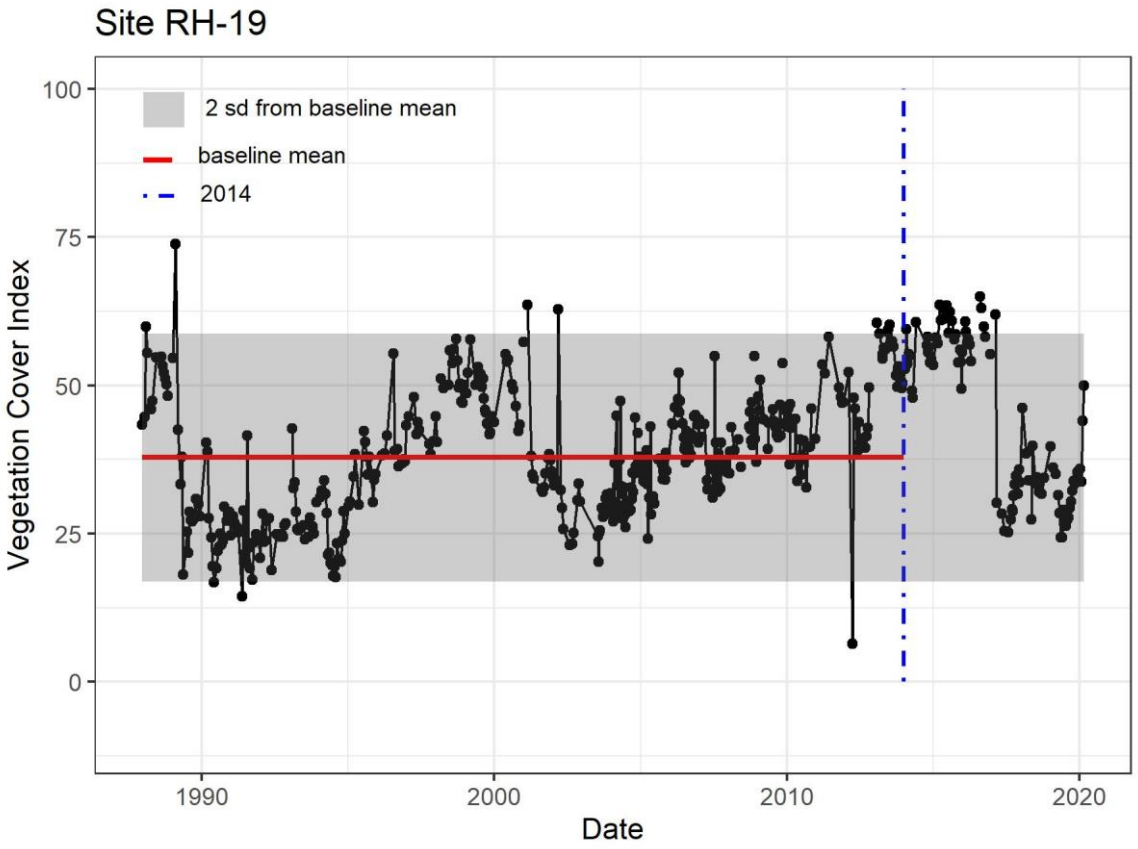
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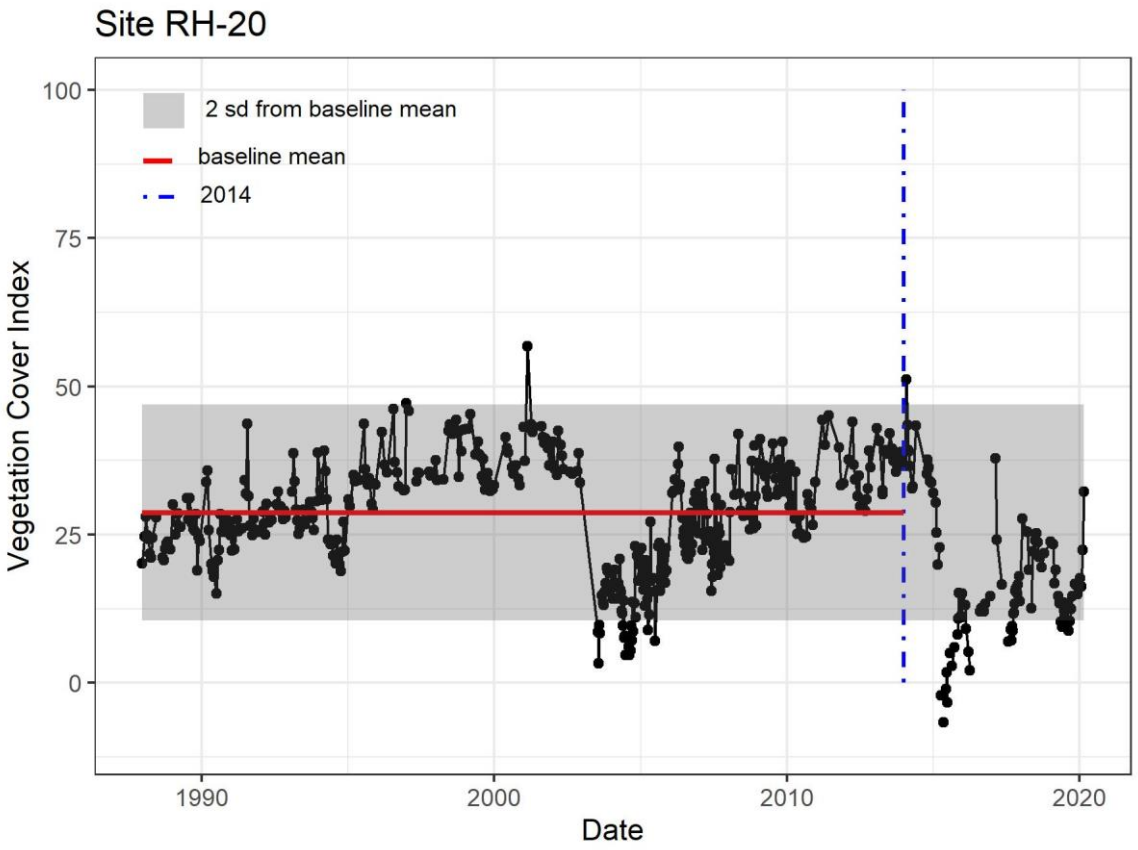
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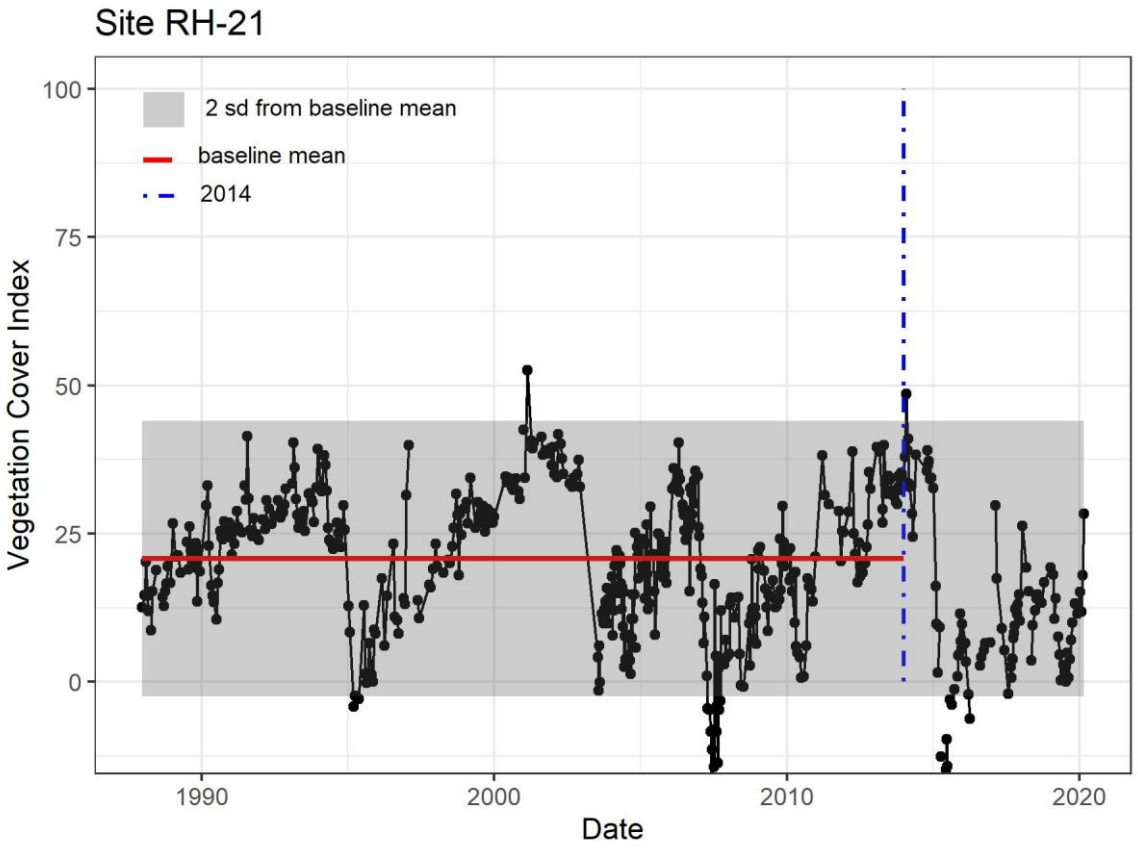
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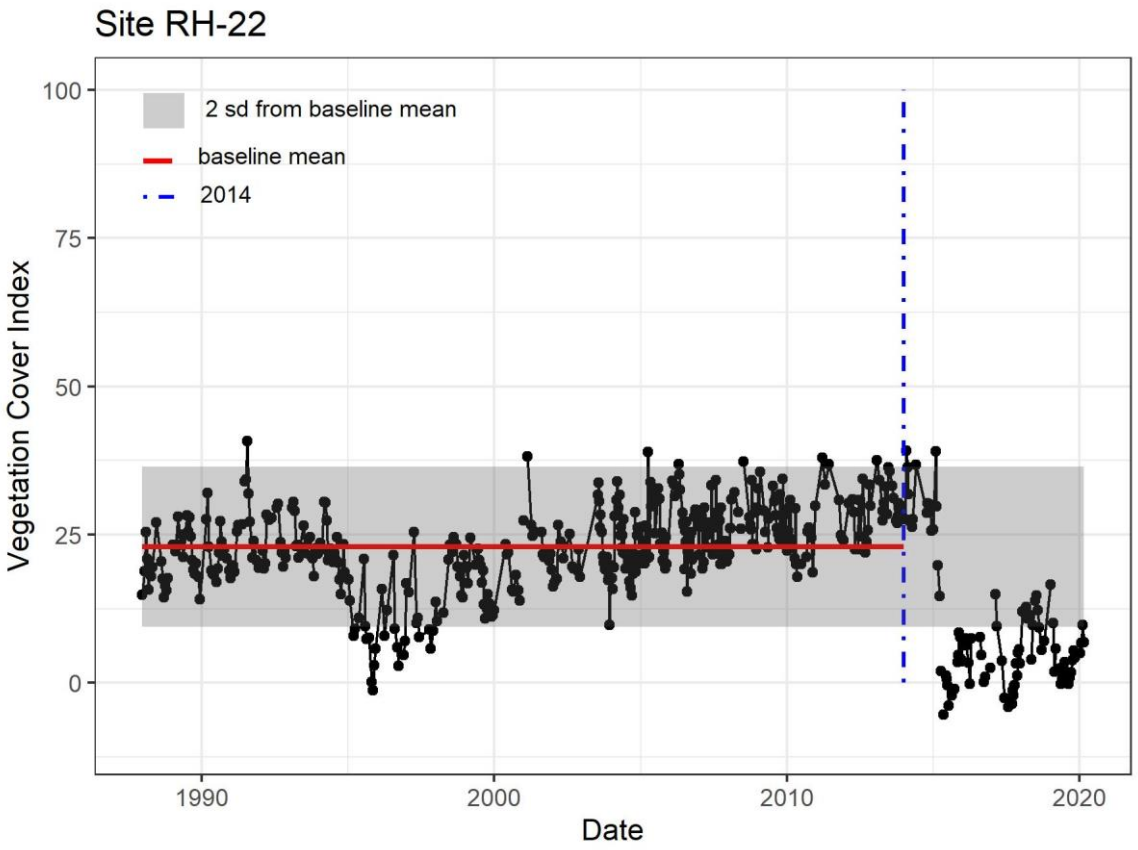
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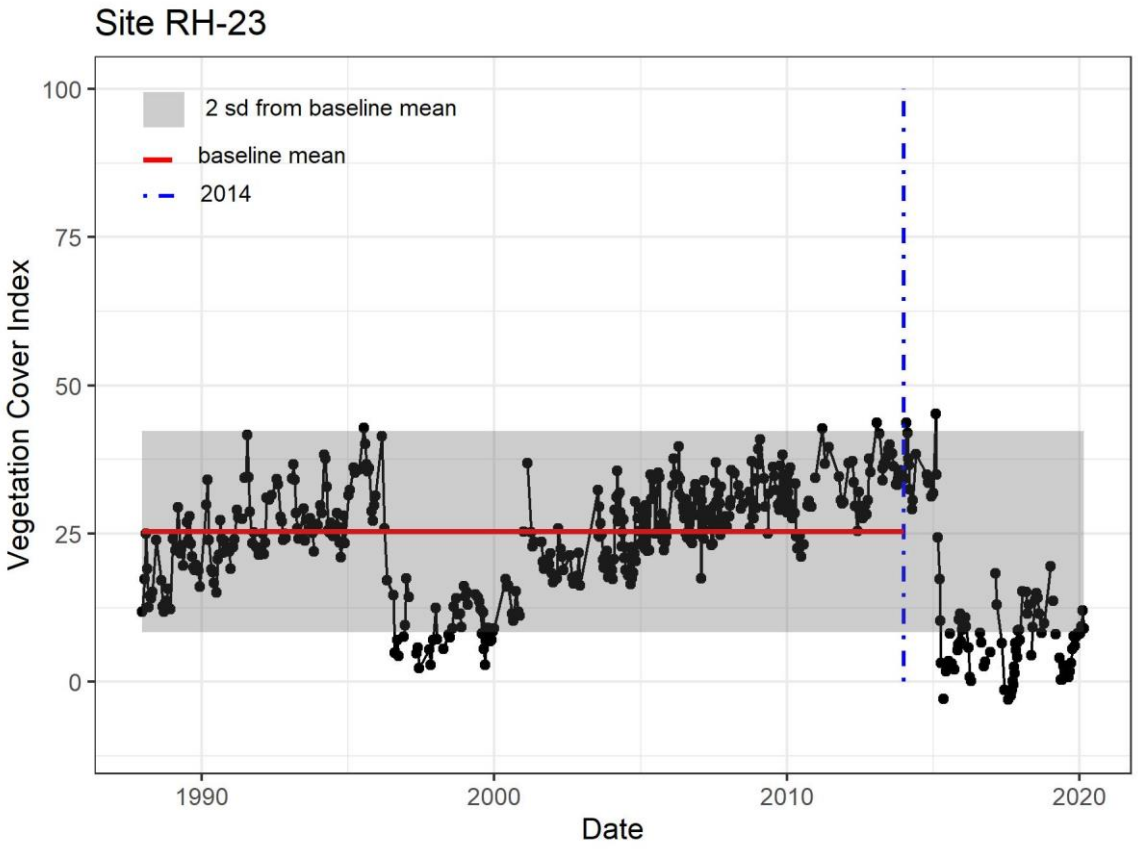
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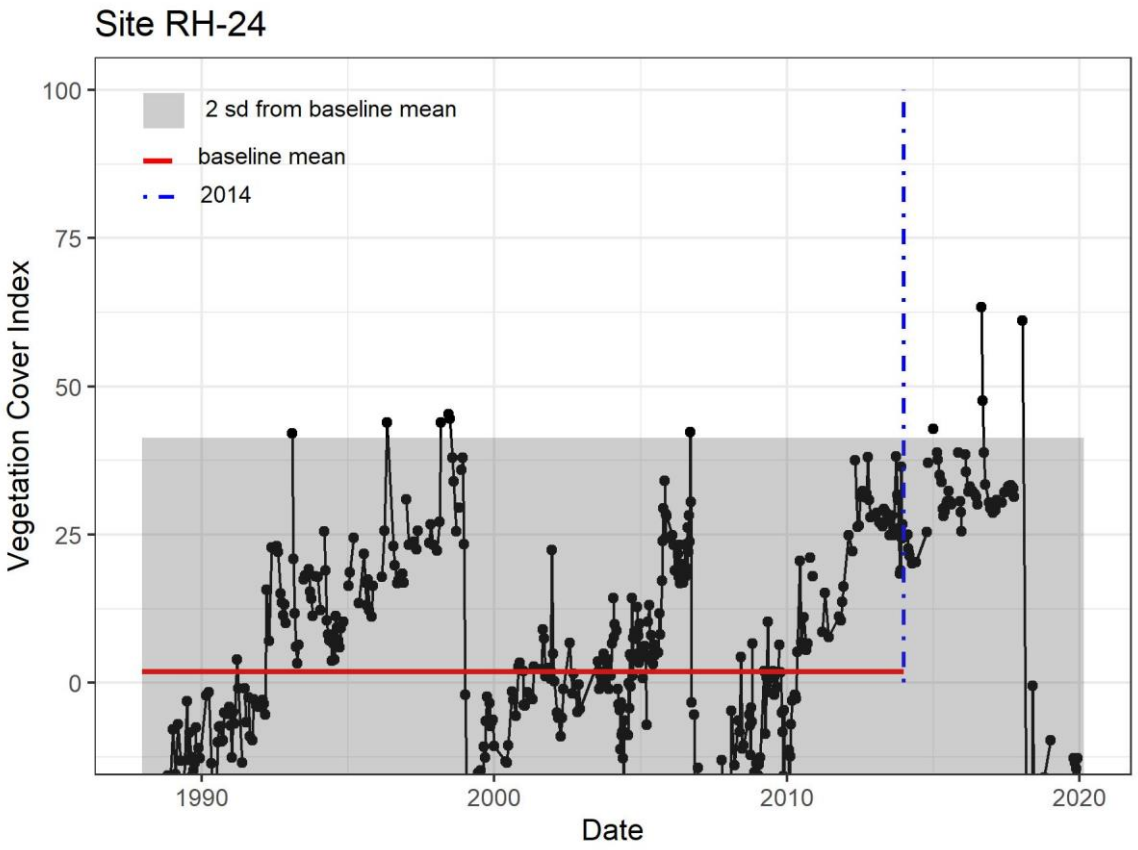
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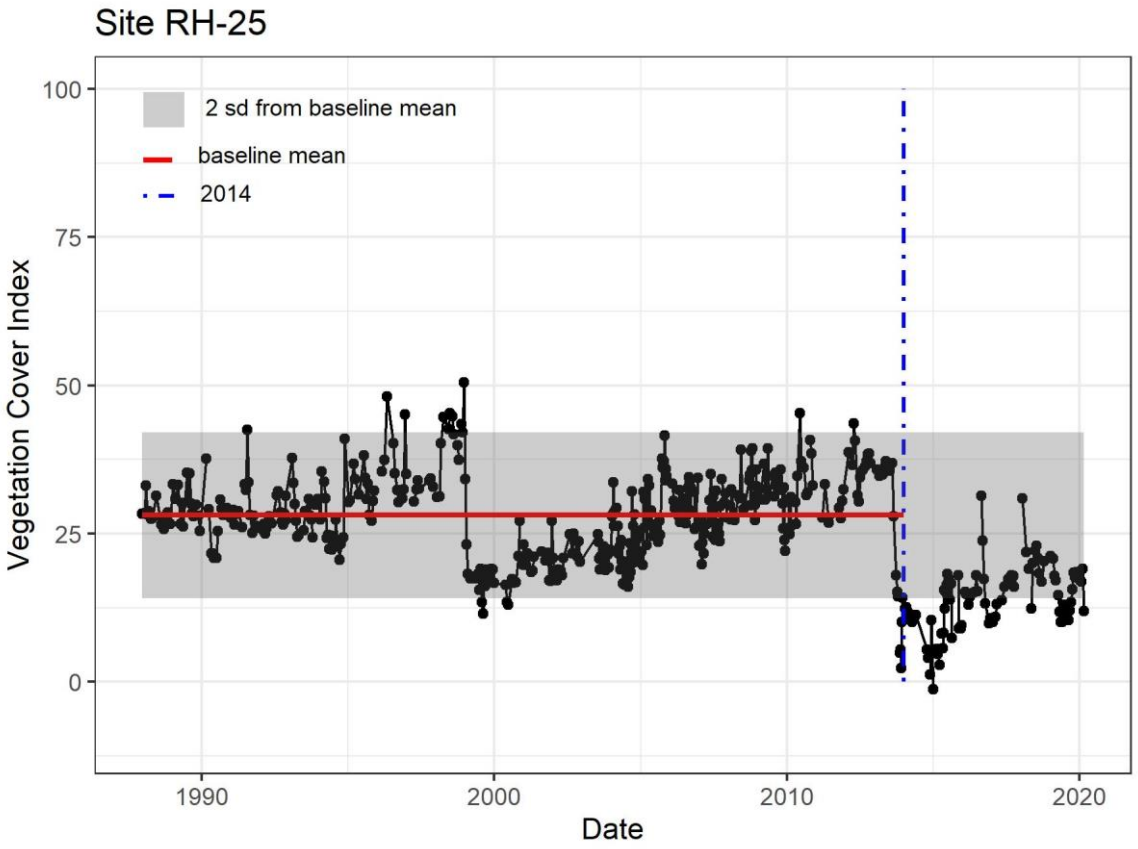
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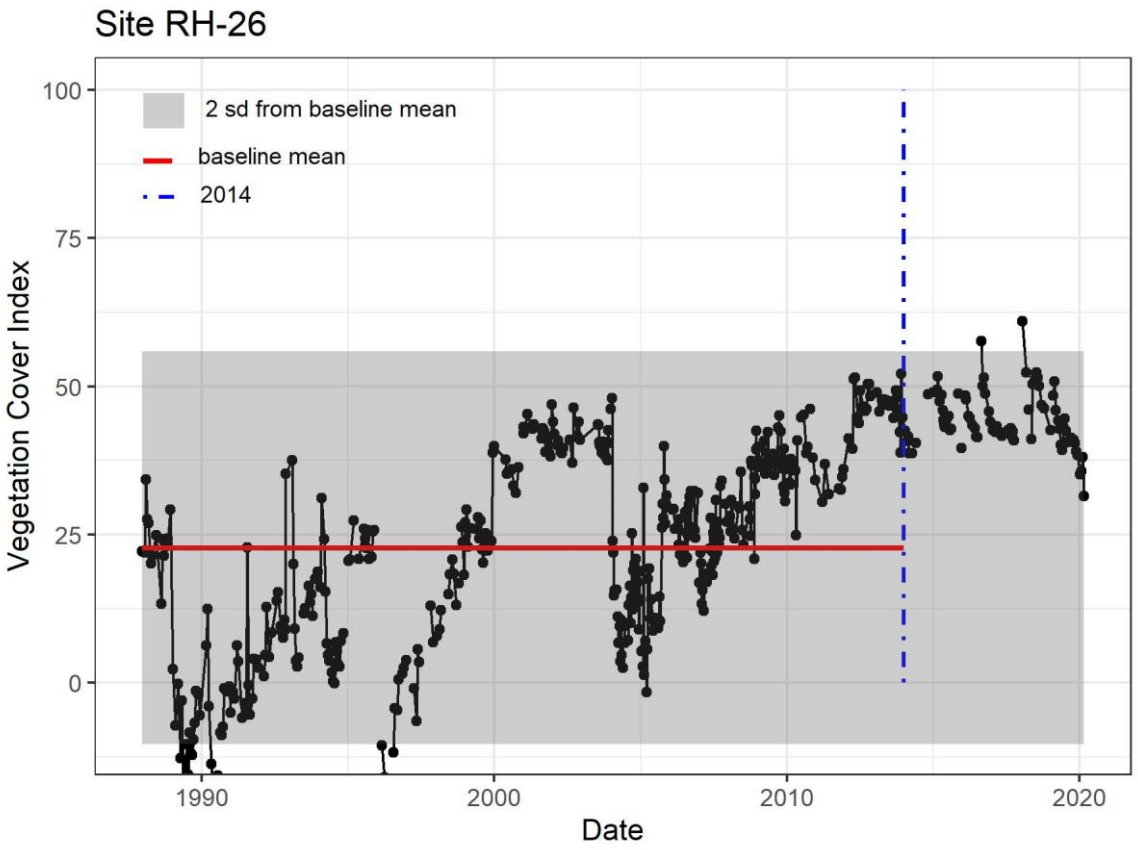
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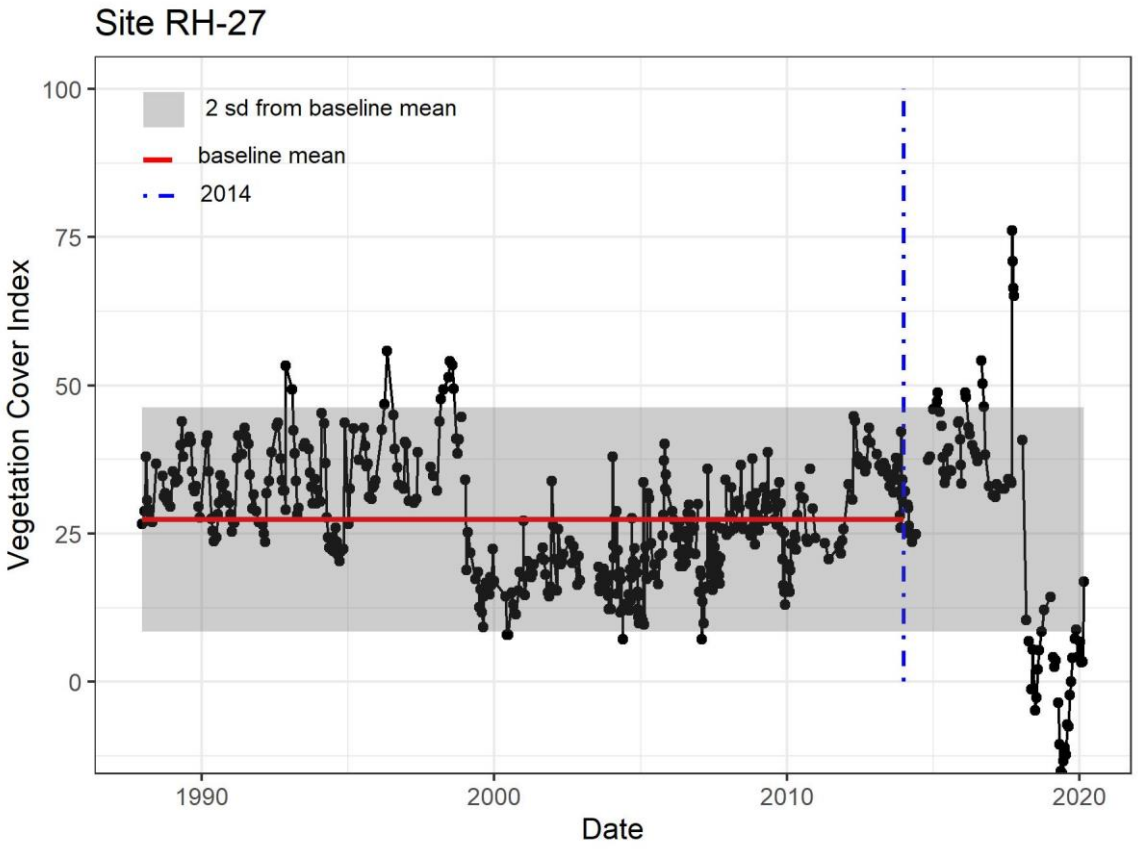
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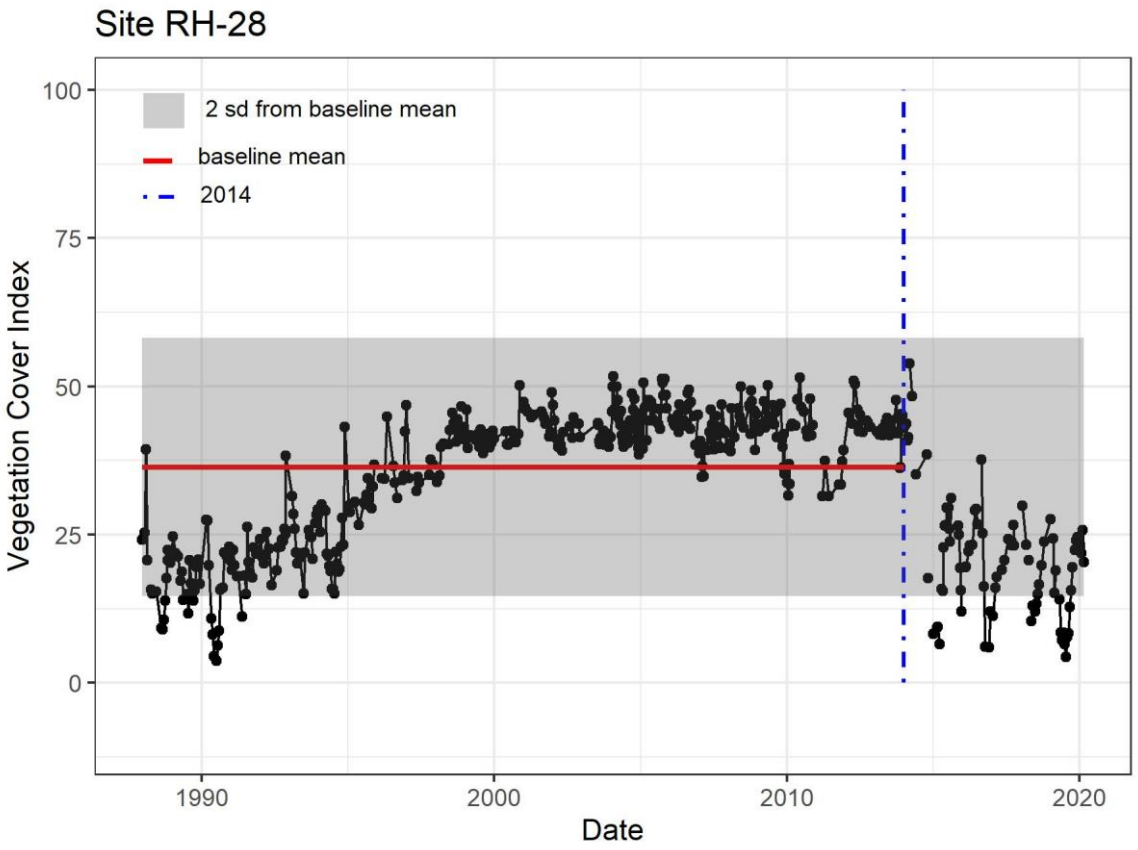
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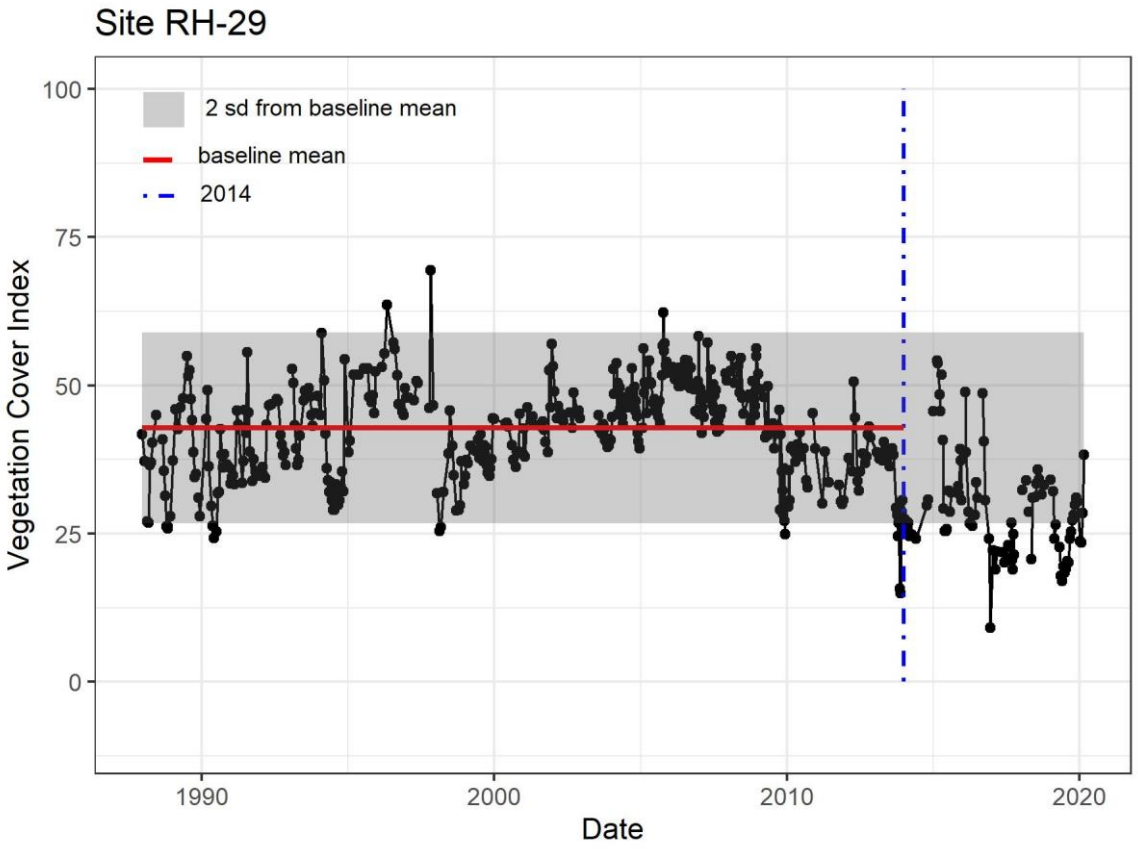
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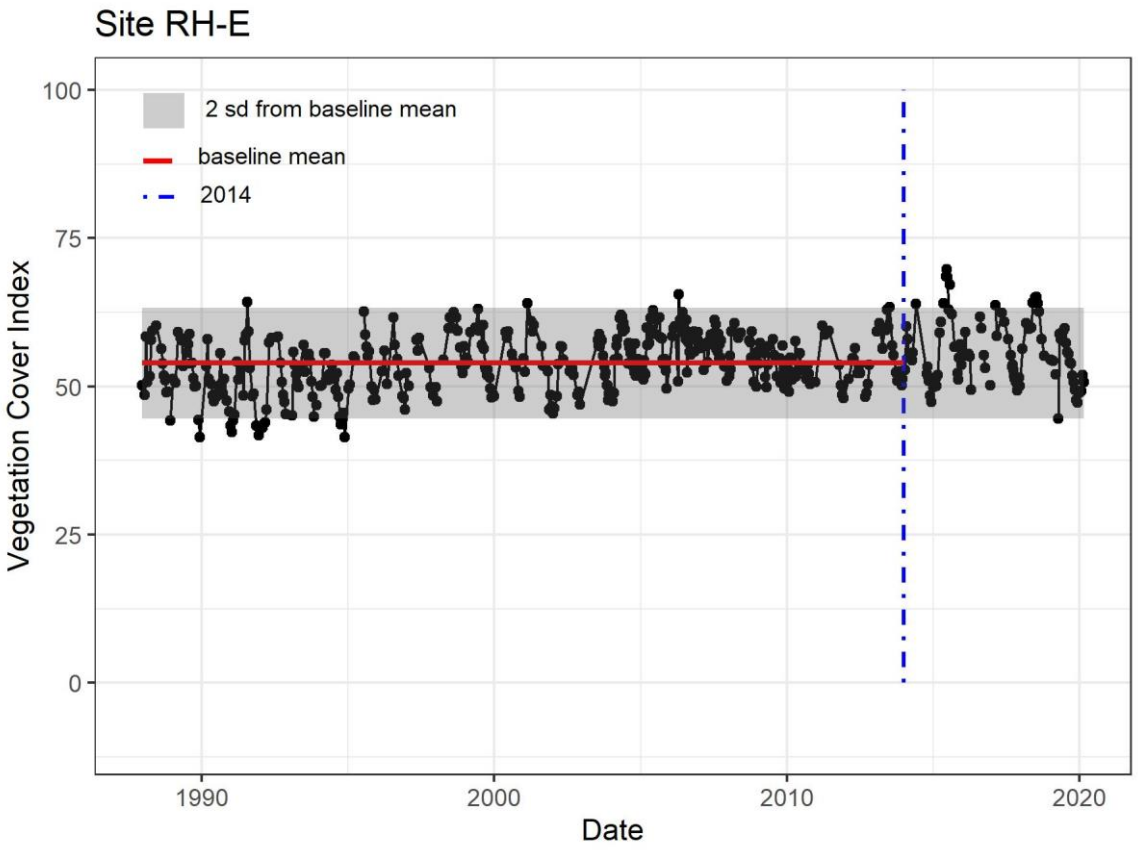
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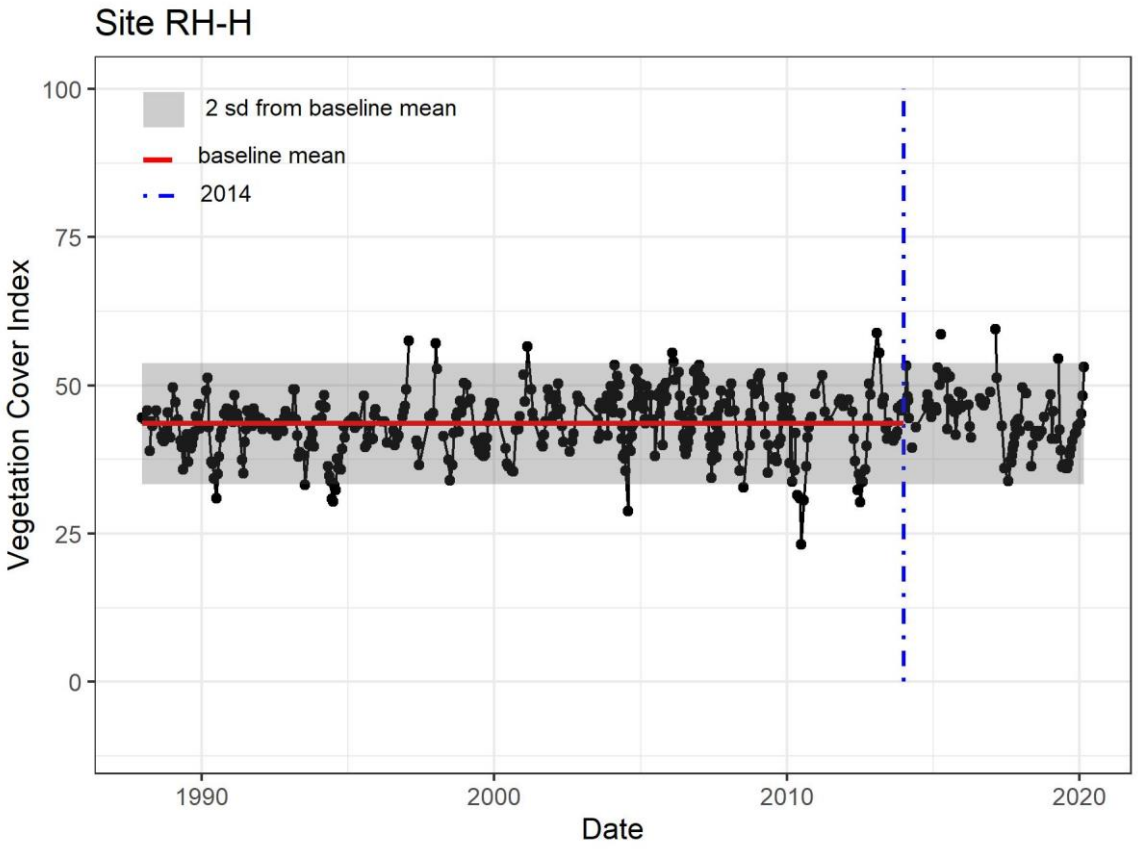
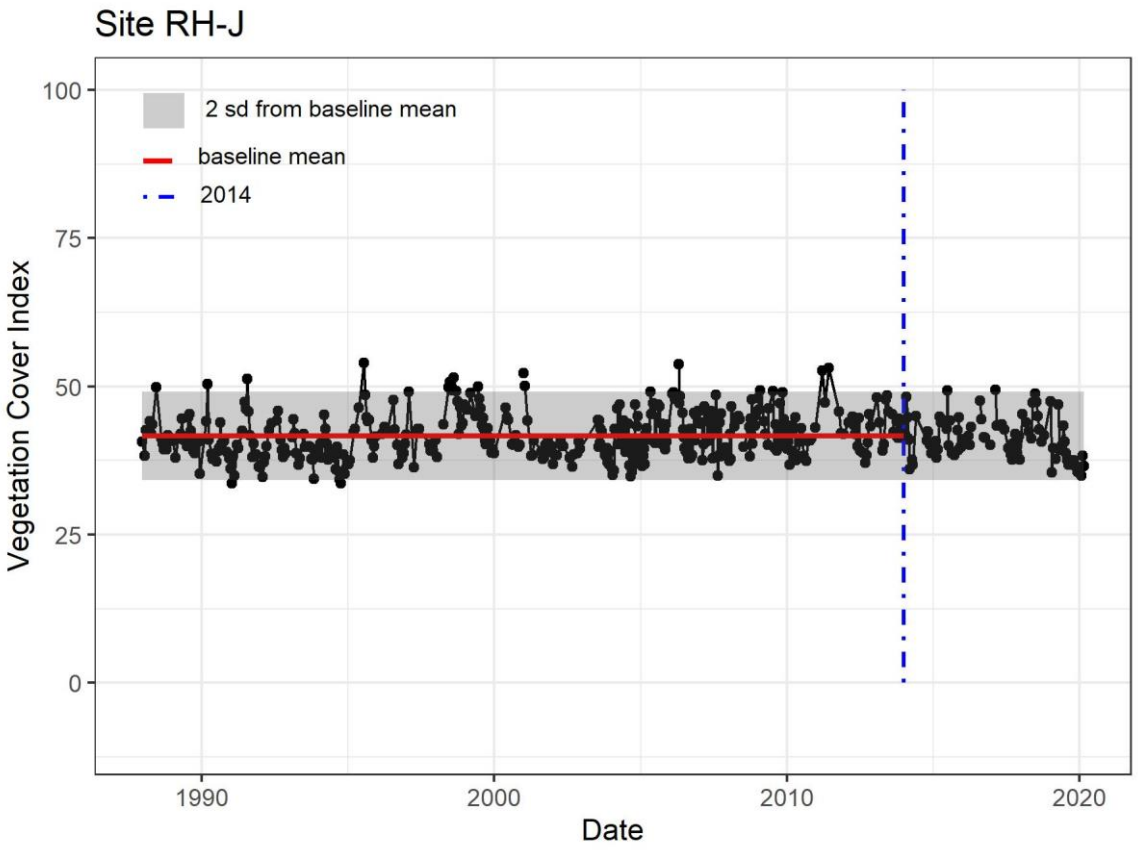
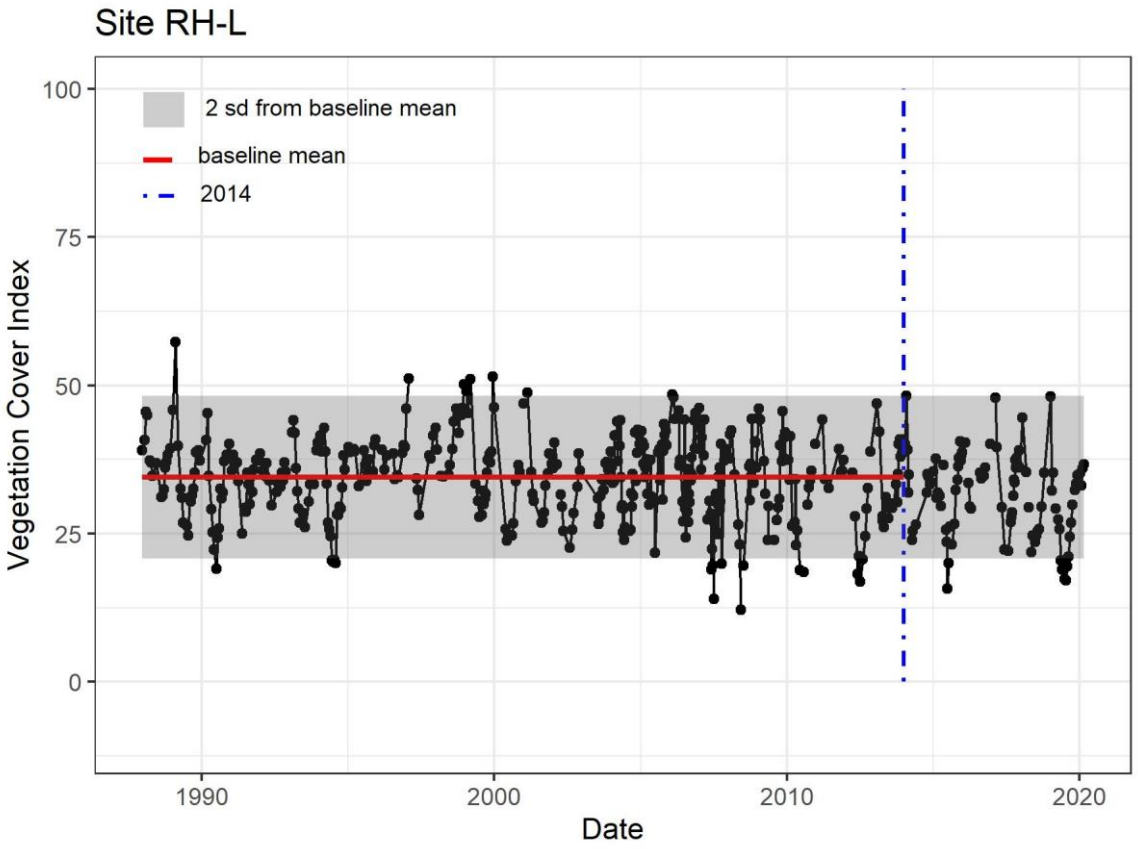
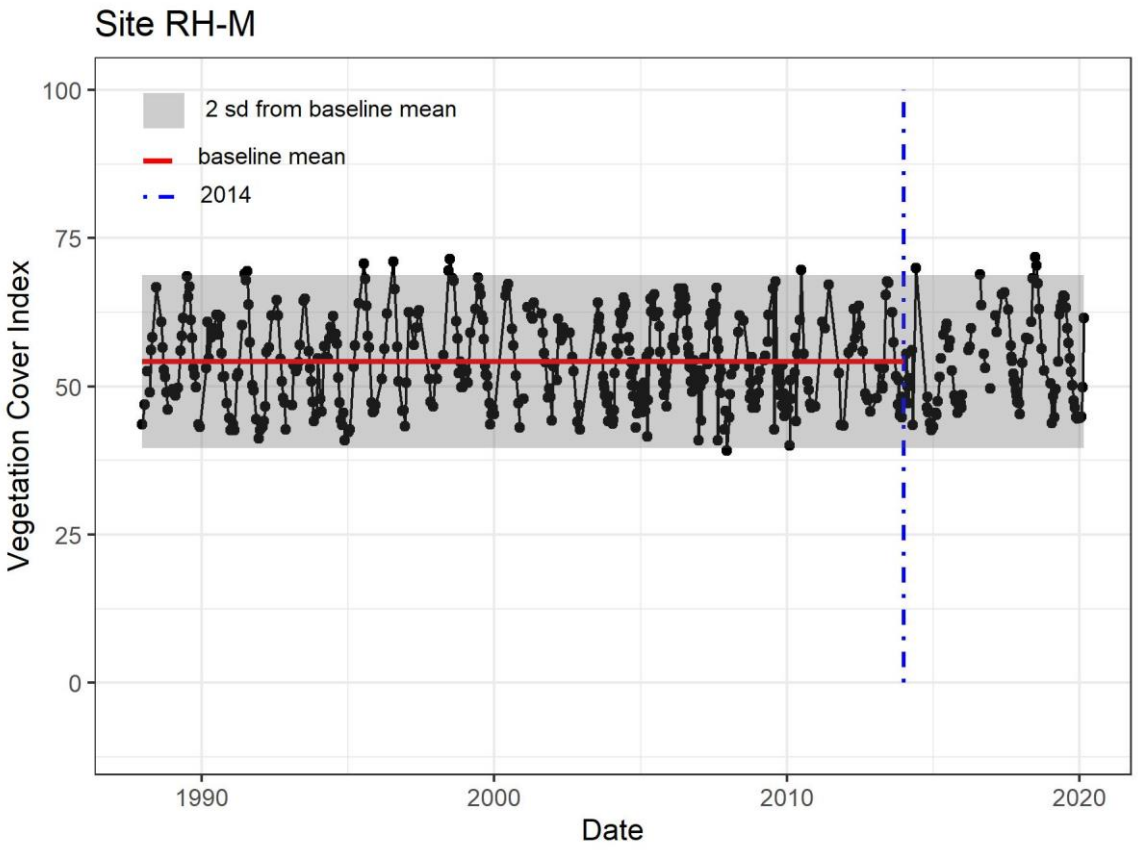
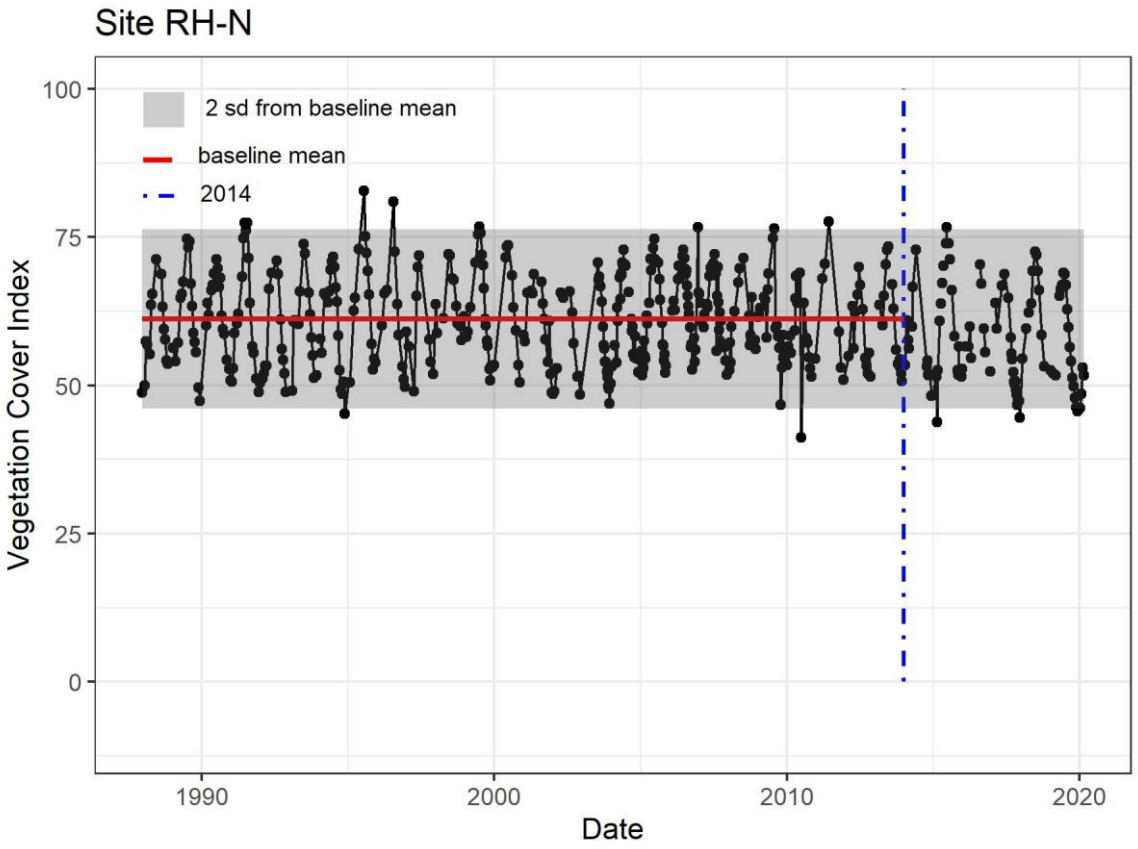
2020
Date

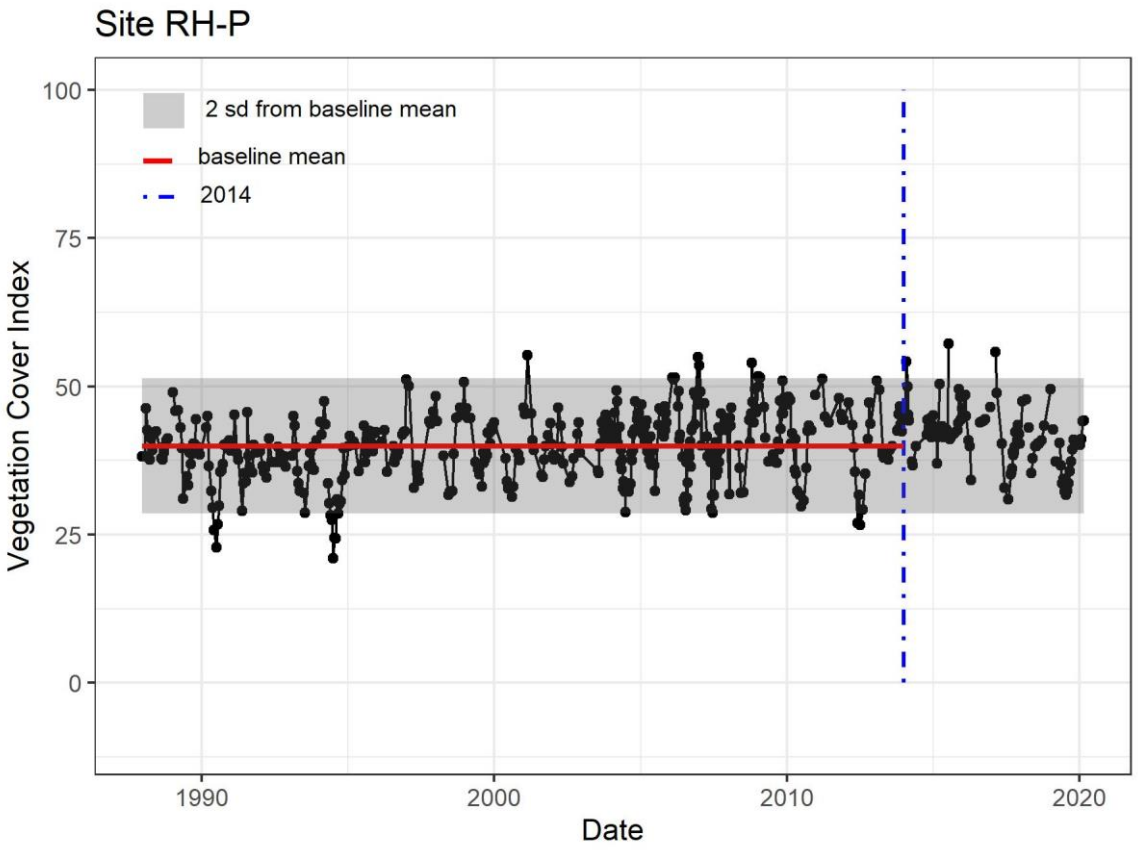

Site RH-H
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

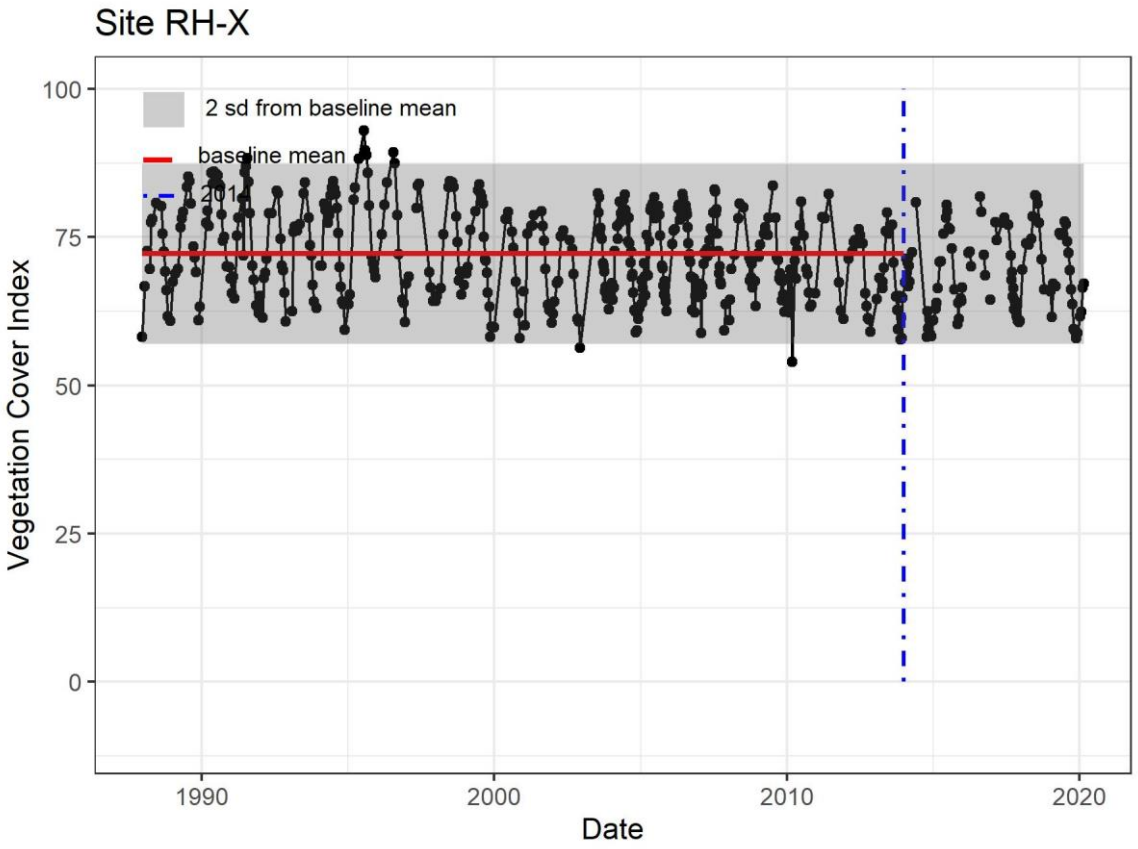

Site RH-J
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

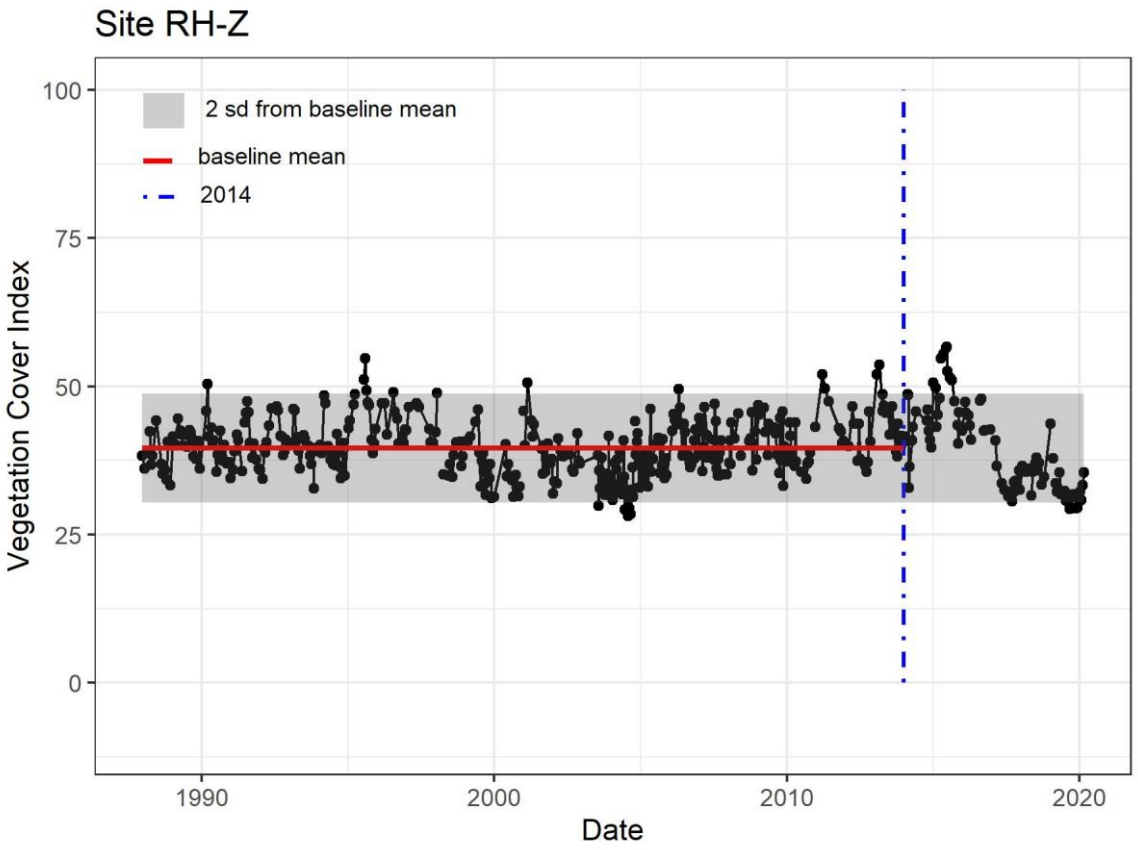

Site RH-L
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site RH-M
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site RH-N
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

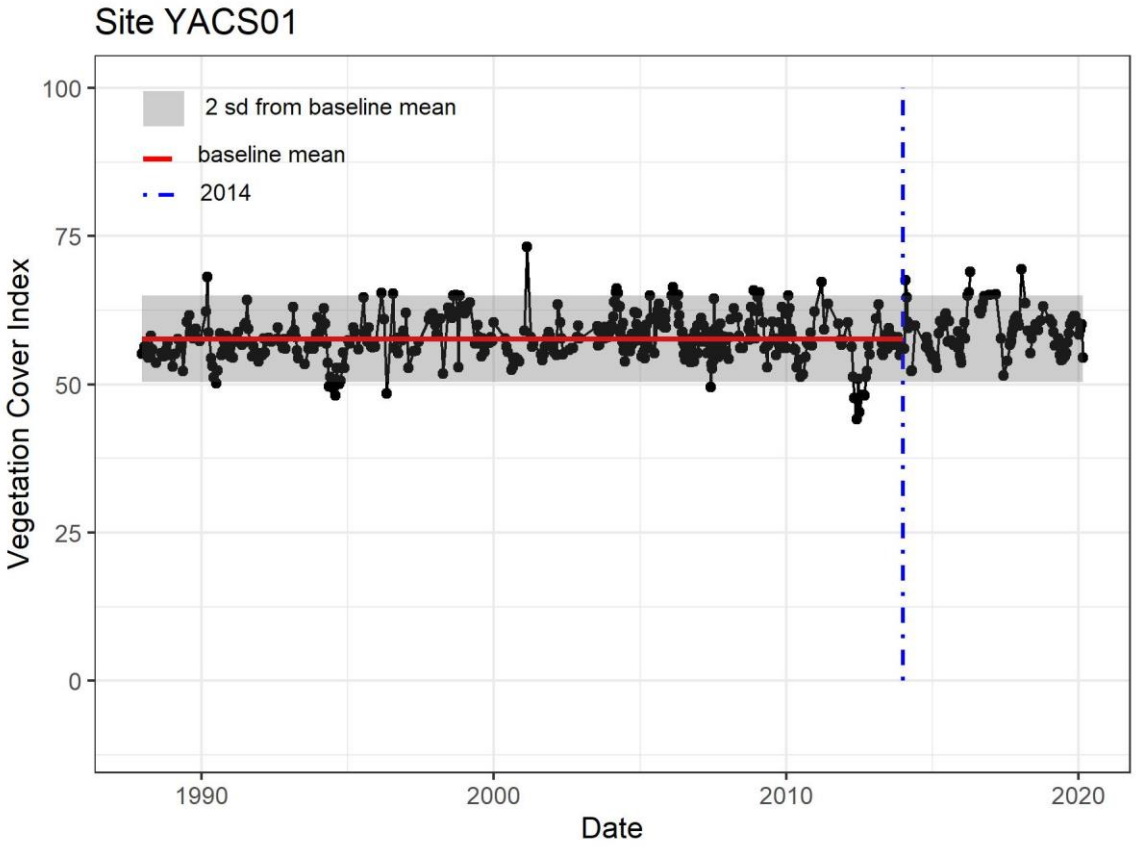

Site RH-P
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

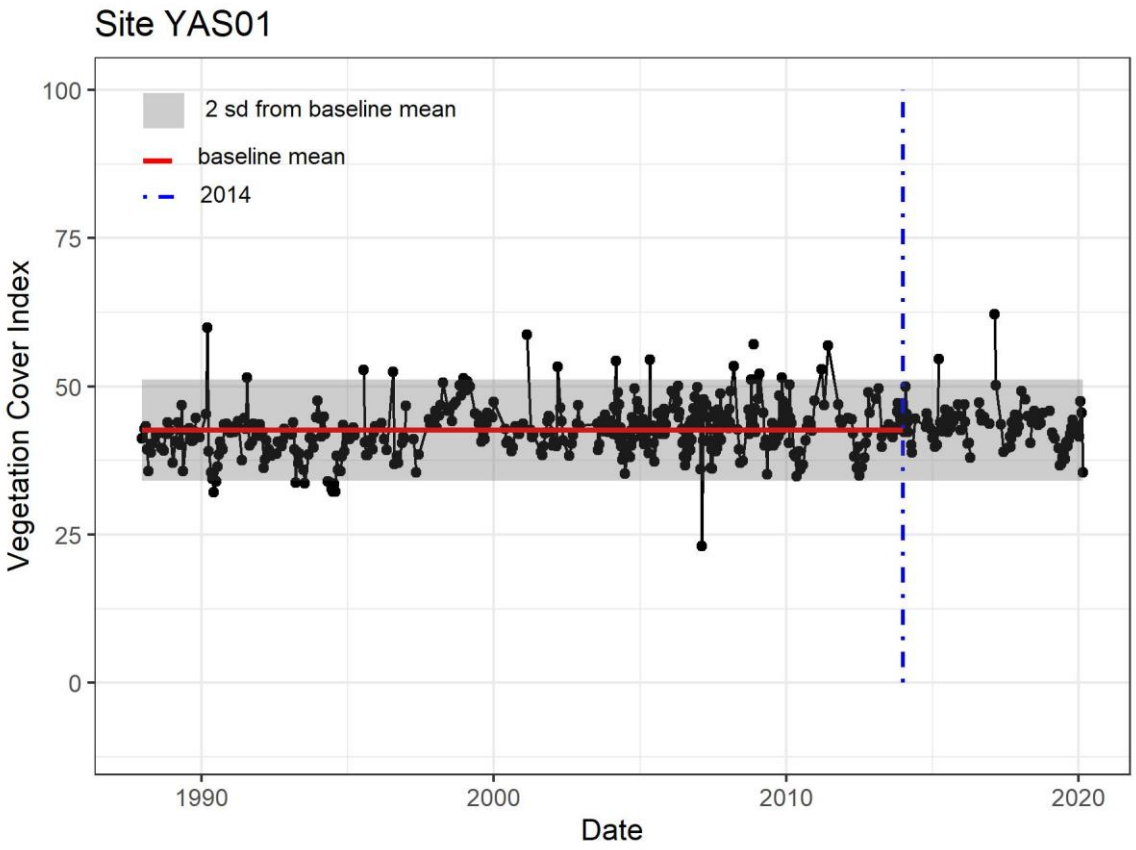

Site RH-X
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

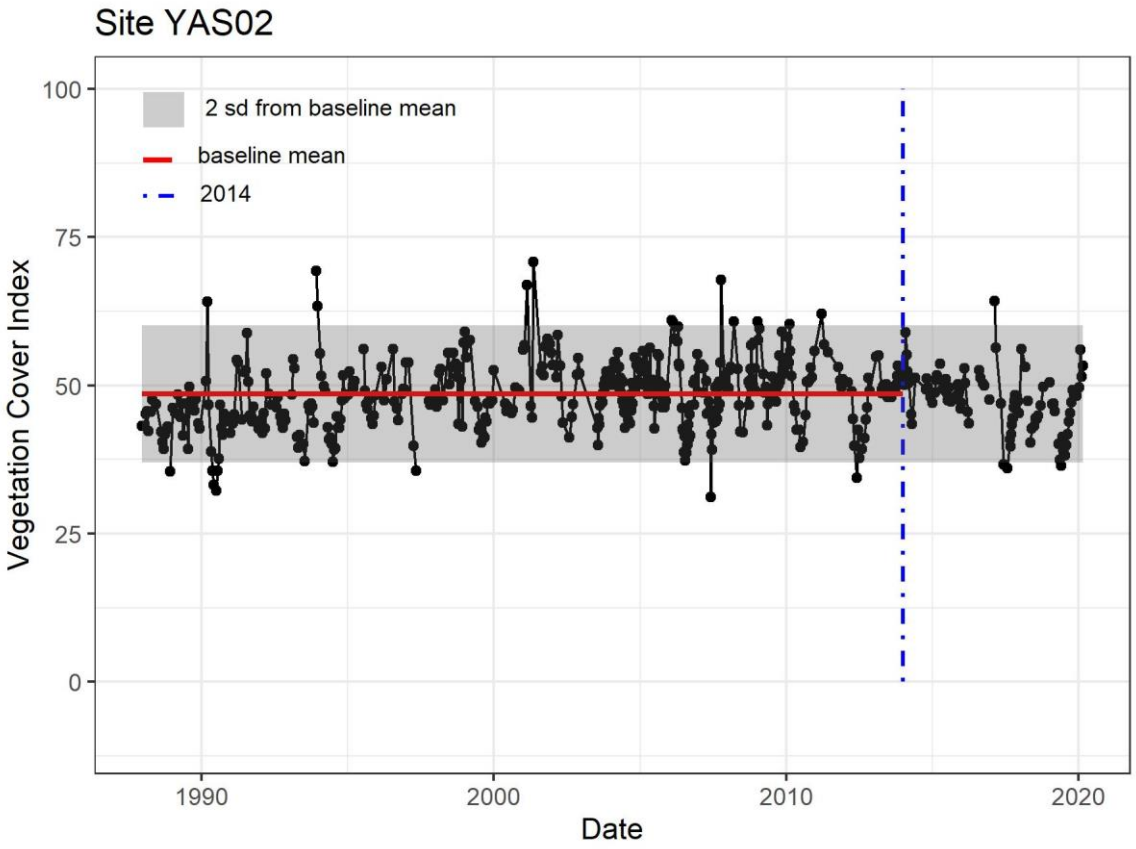

Site RH-Z
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

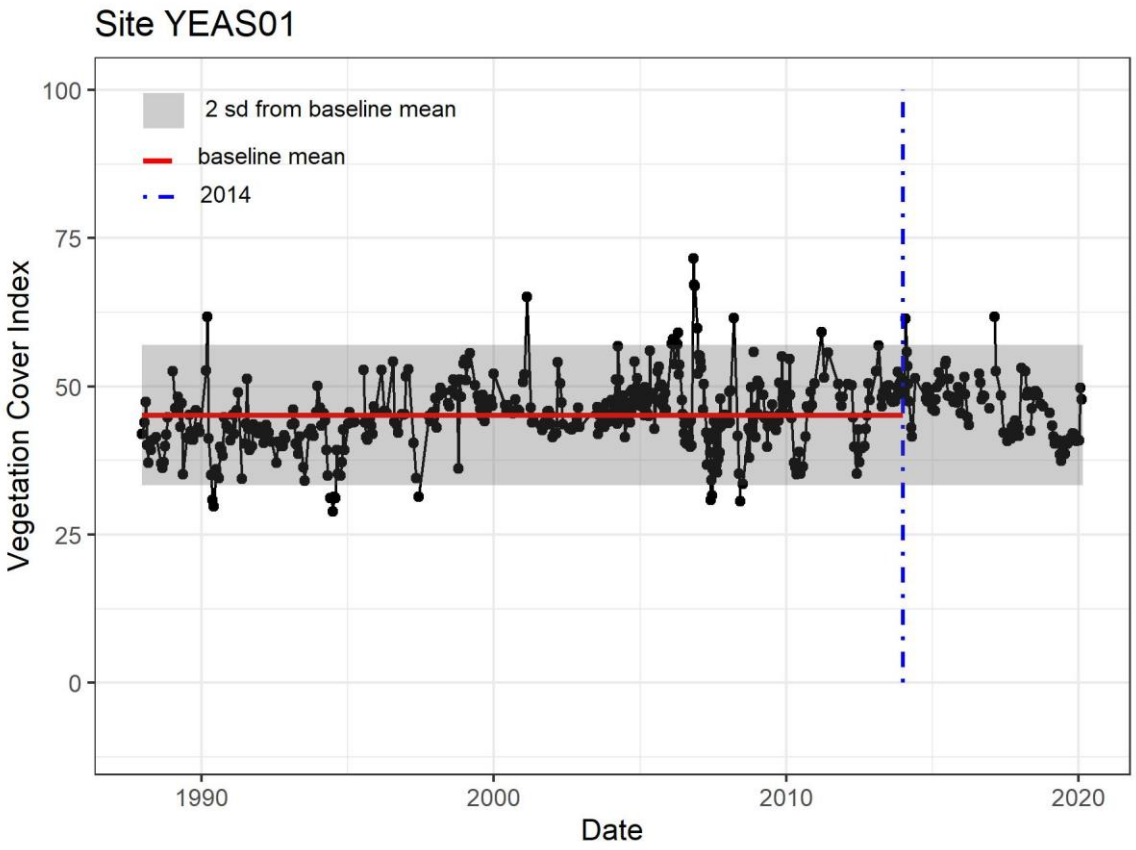
2.4 Time series plots from Yarraloola

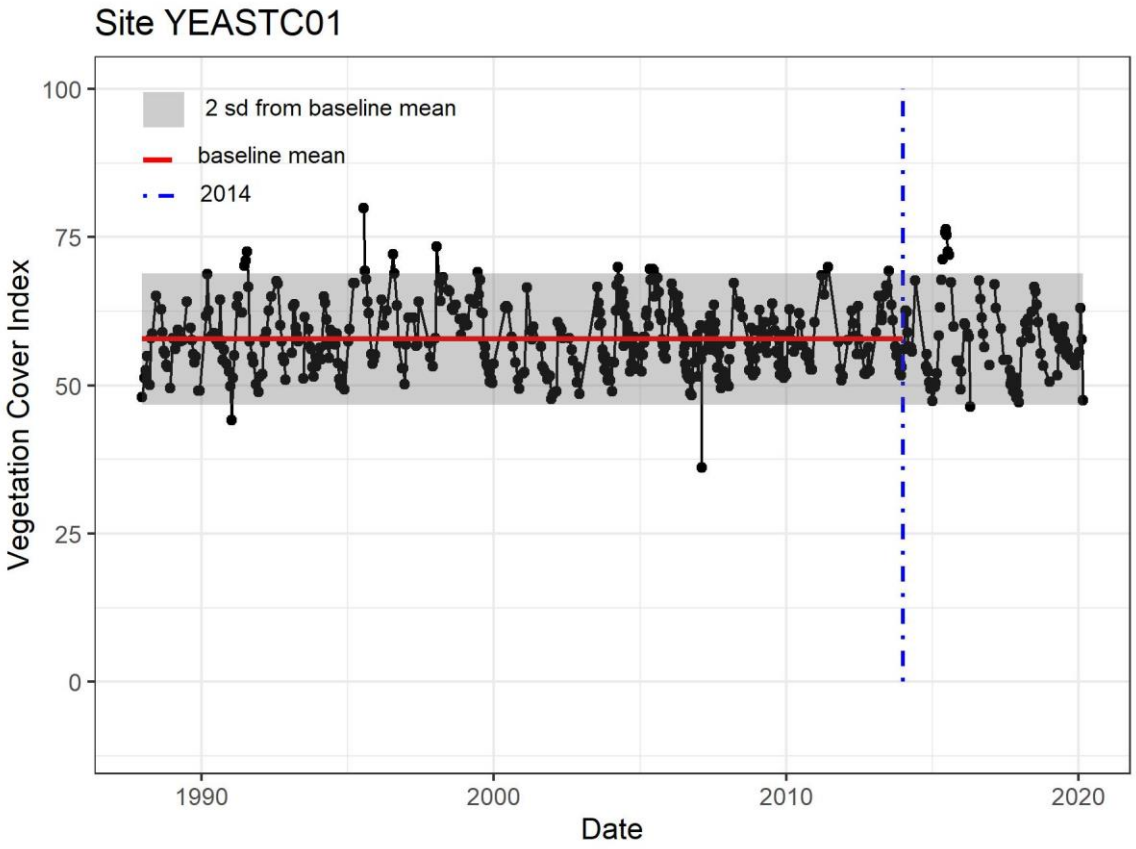
The time series vegetation cover graphs for Yarraloola are shown below. The red line is the baseline (1988 to 2014) mean, the grey area shows the range within two standard deviations from this mean and the blue dashed line indicates the end of the baseline period (2014).

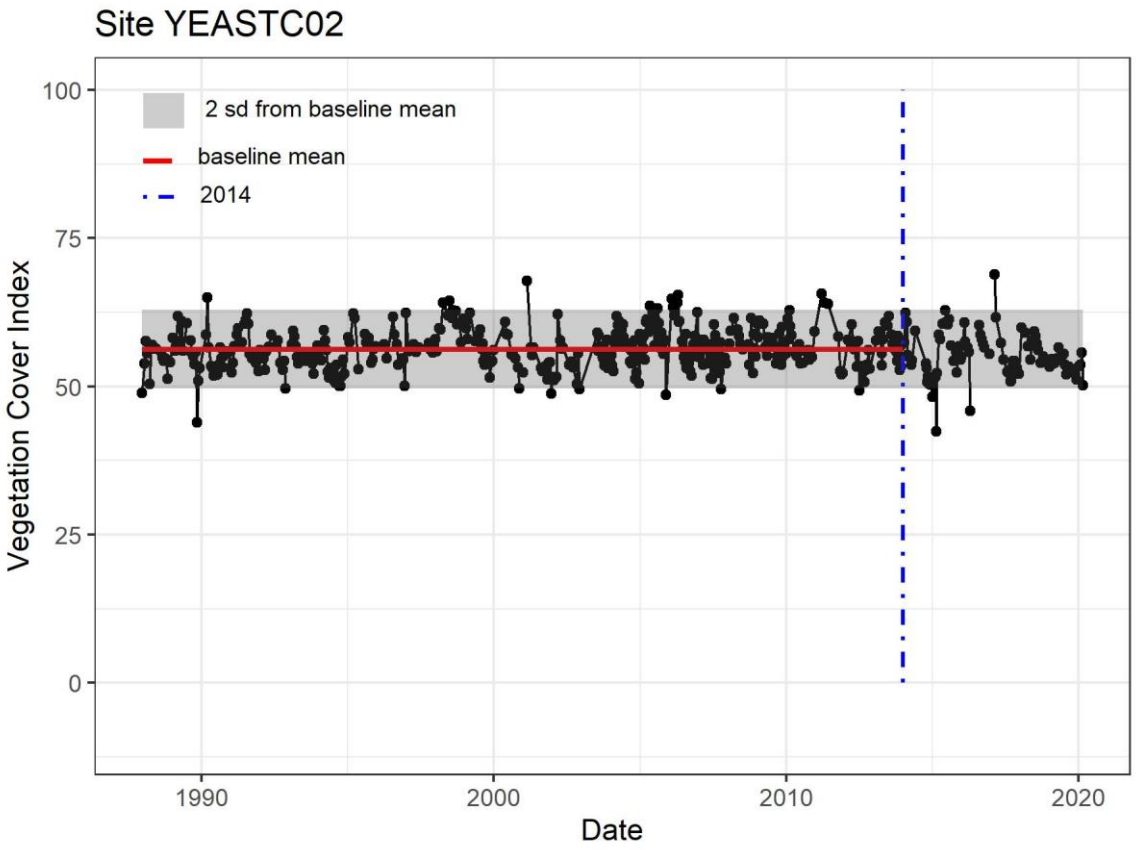


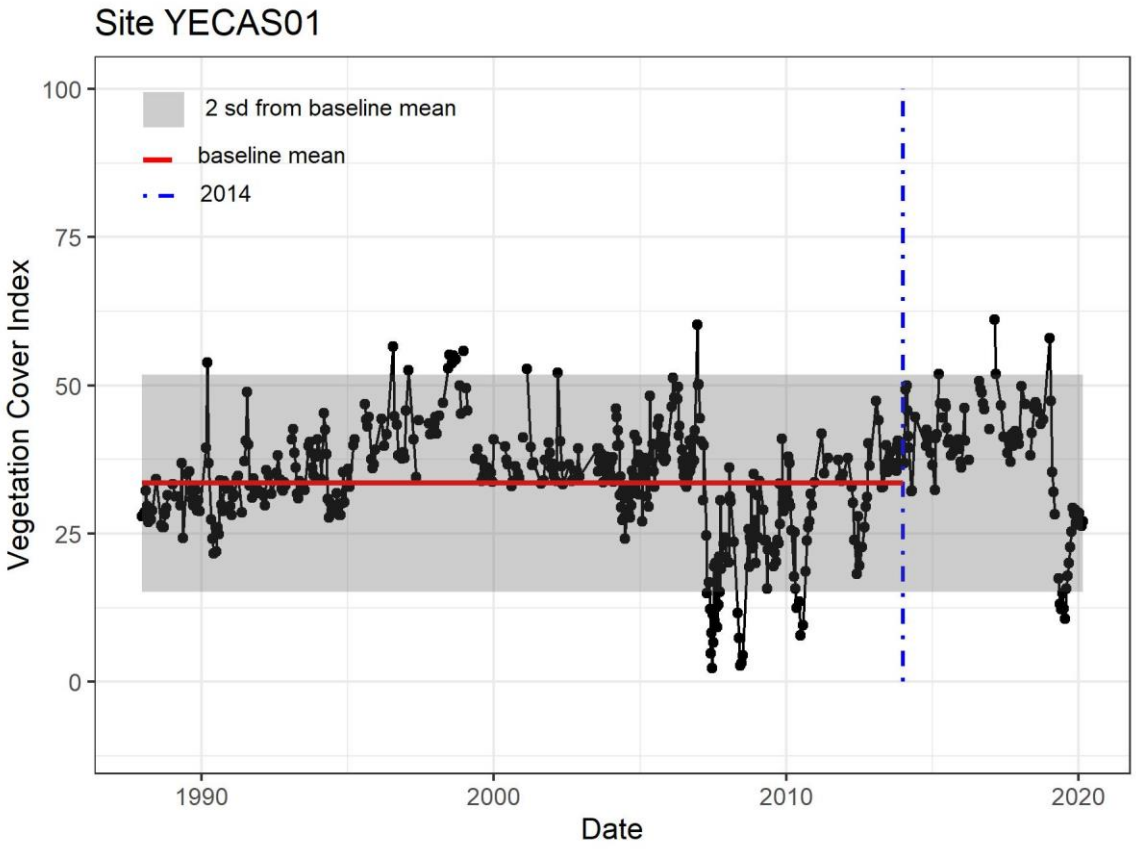

Site YAS01
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

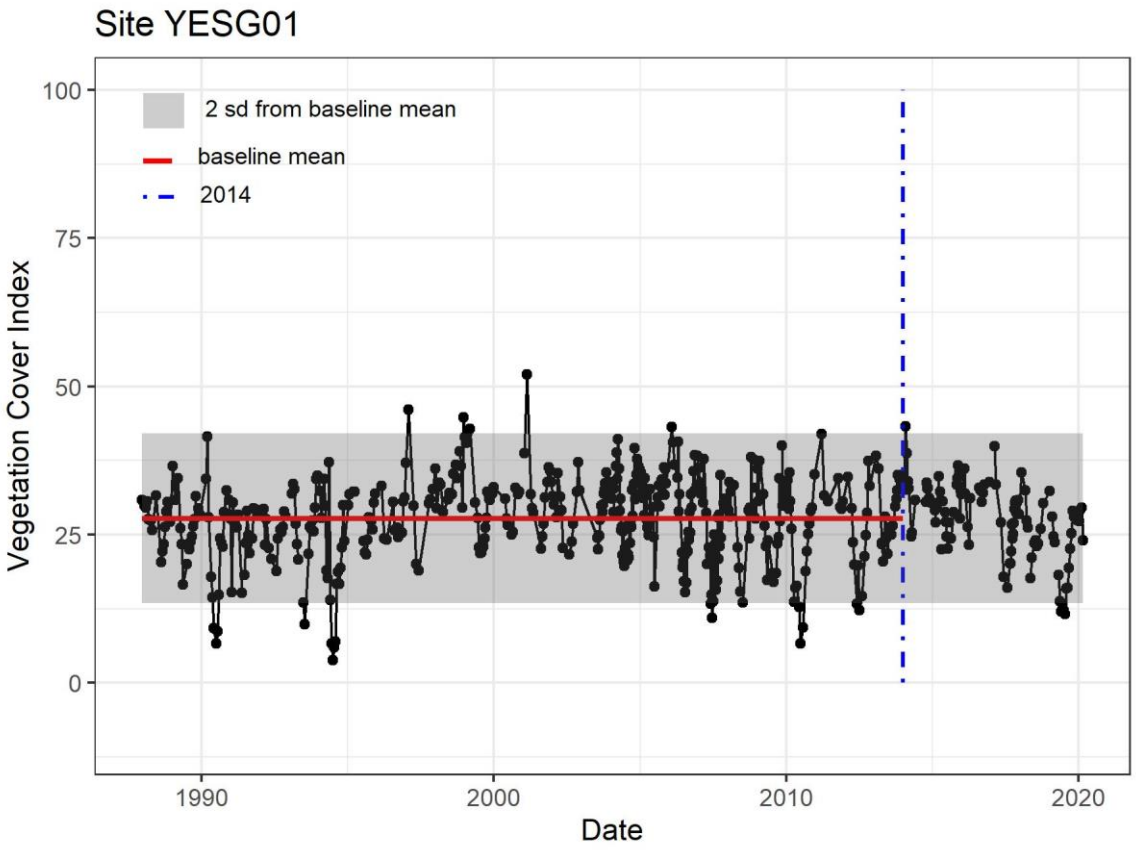

Site YAS02
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

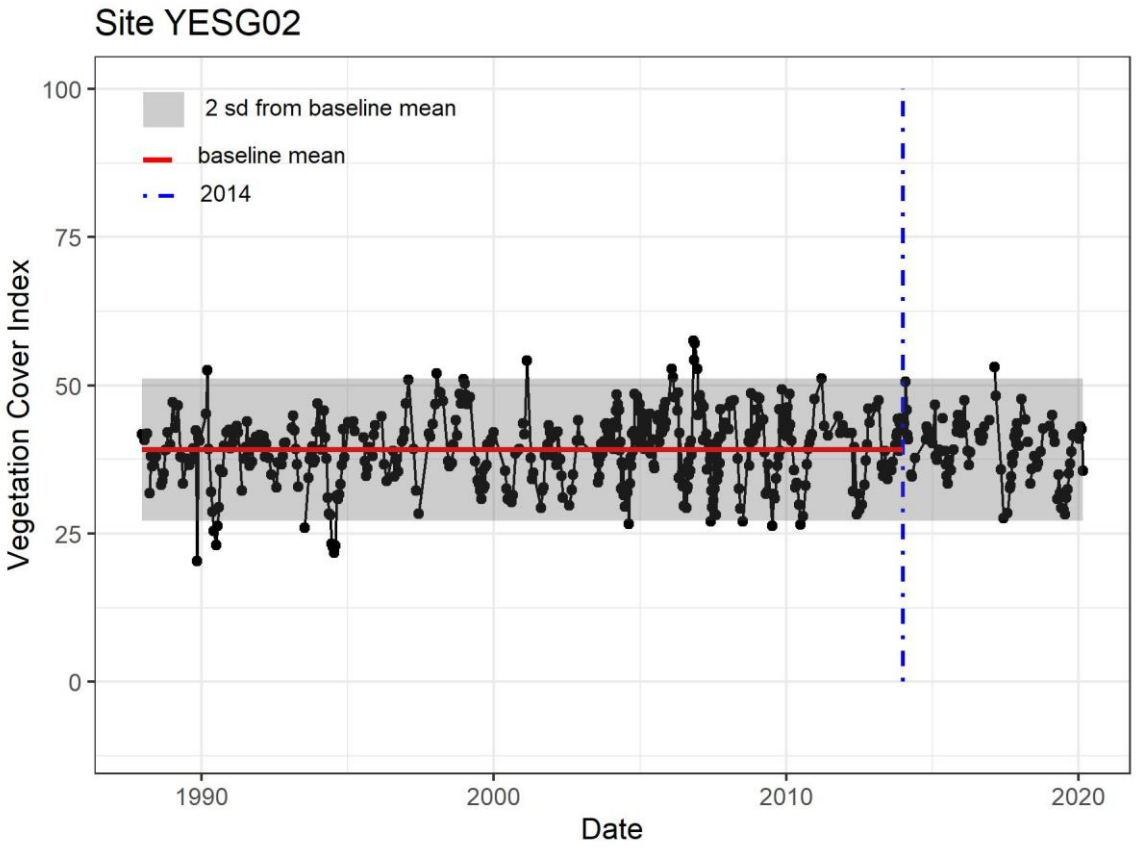

Site YEAS01
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

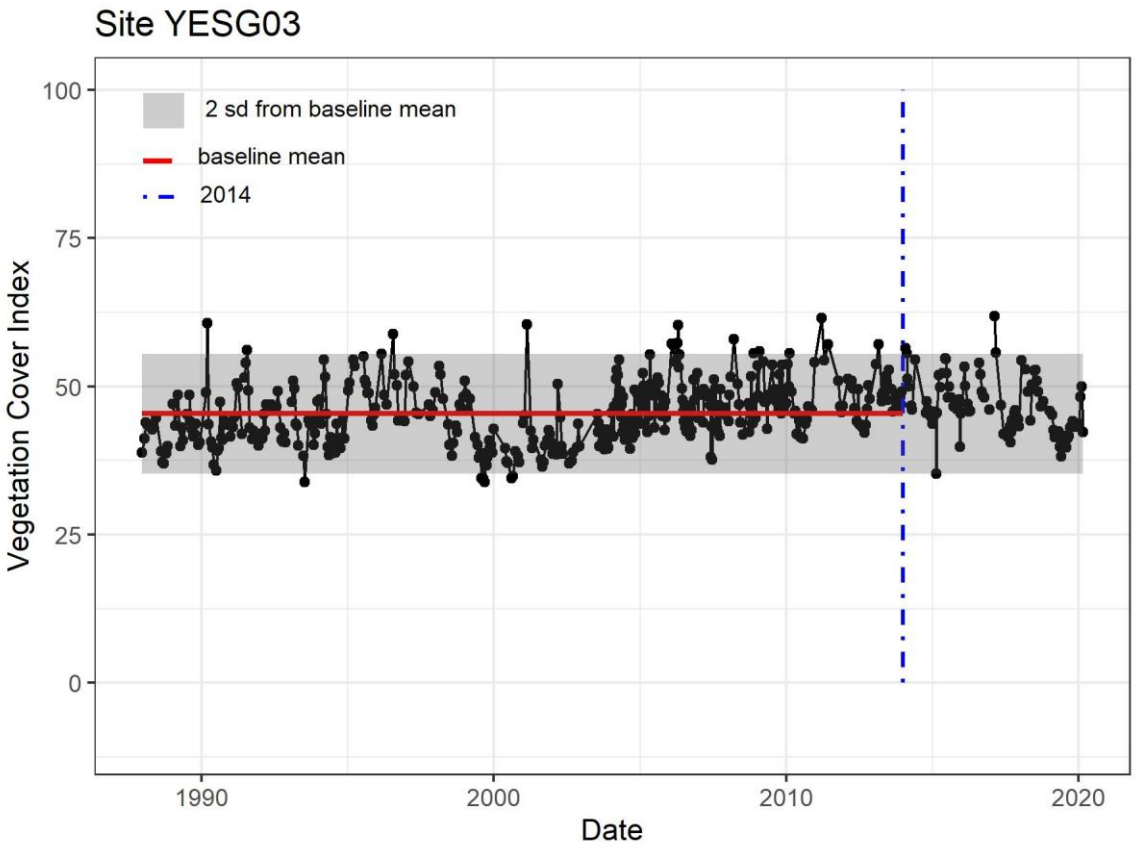

Site YEASTC01
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

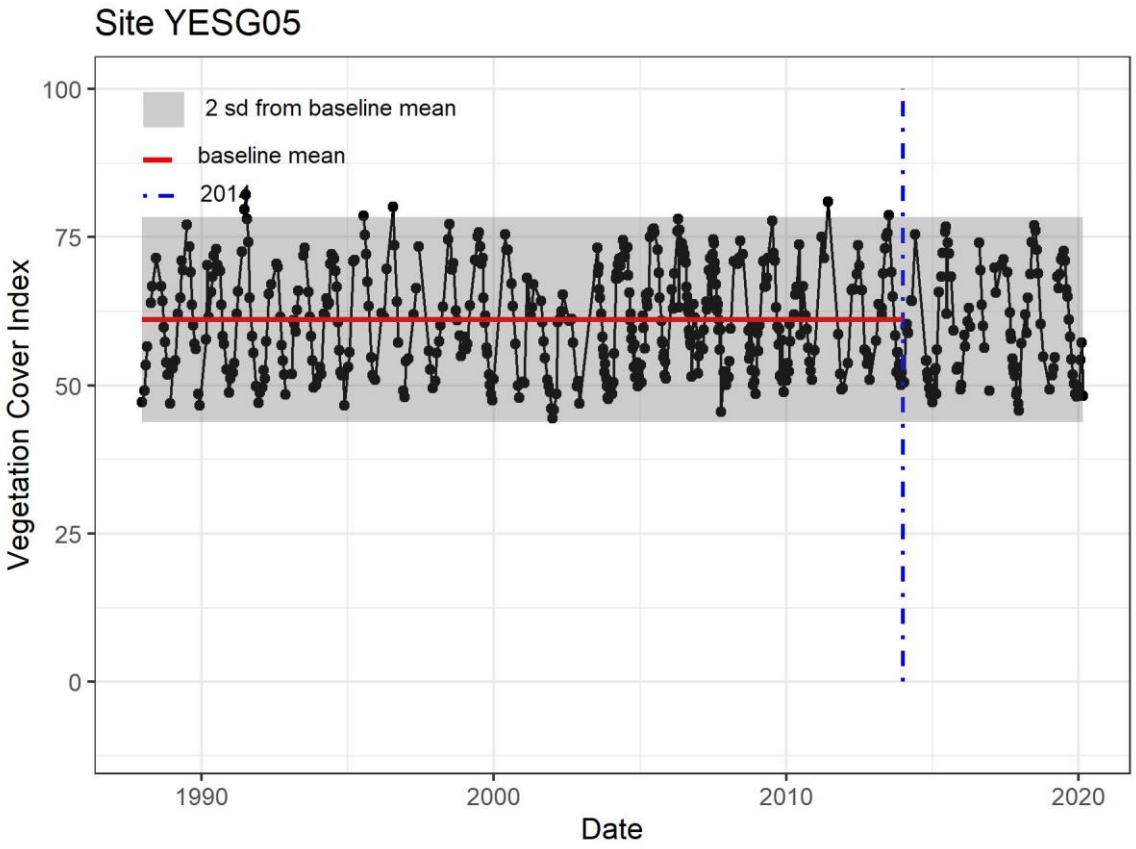

Site YEASTC02
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

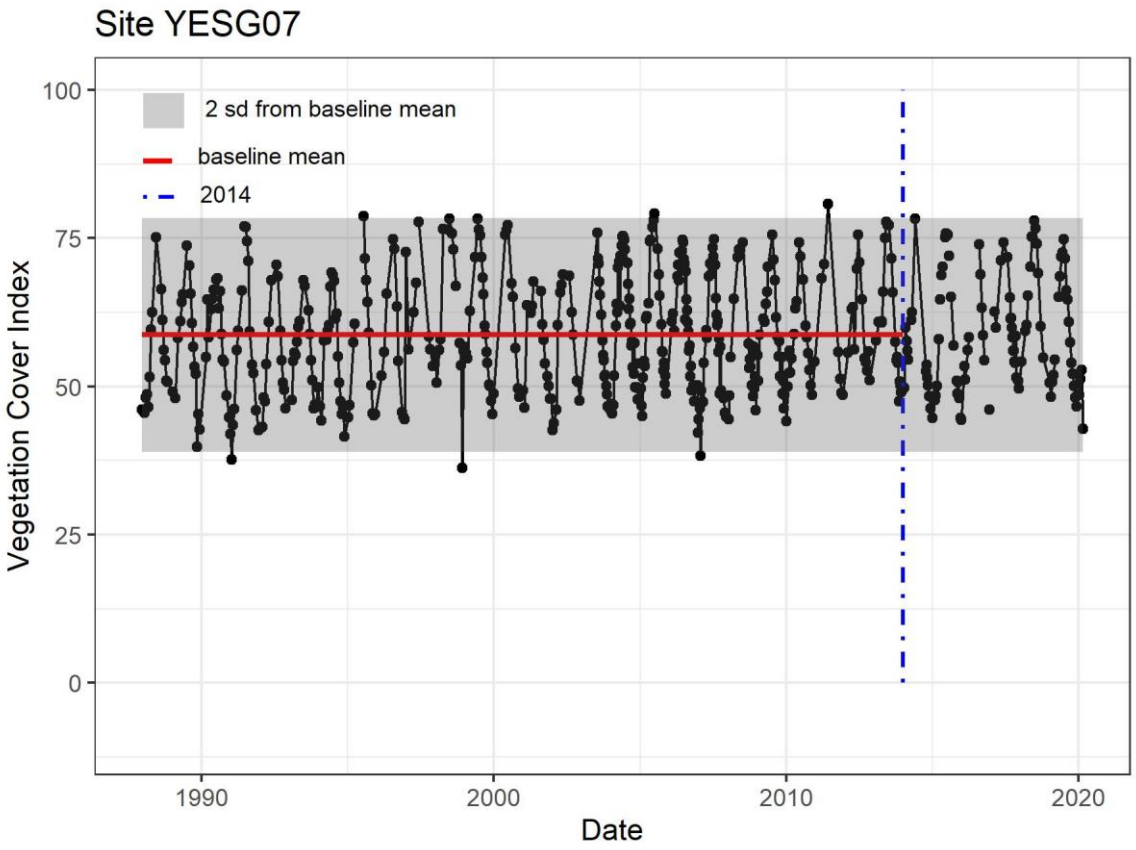

Site YECAS01
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

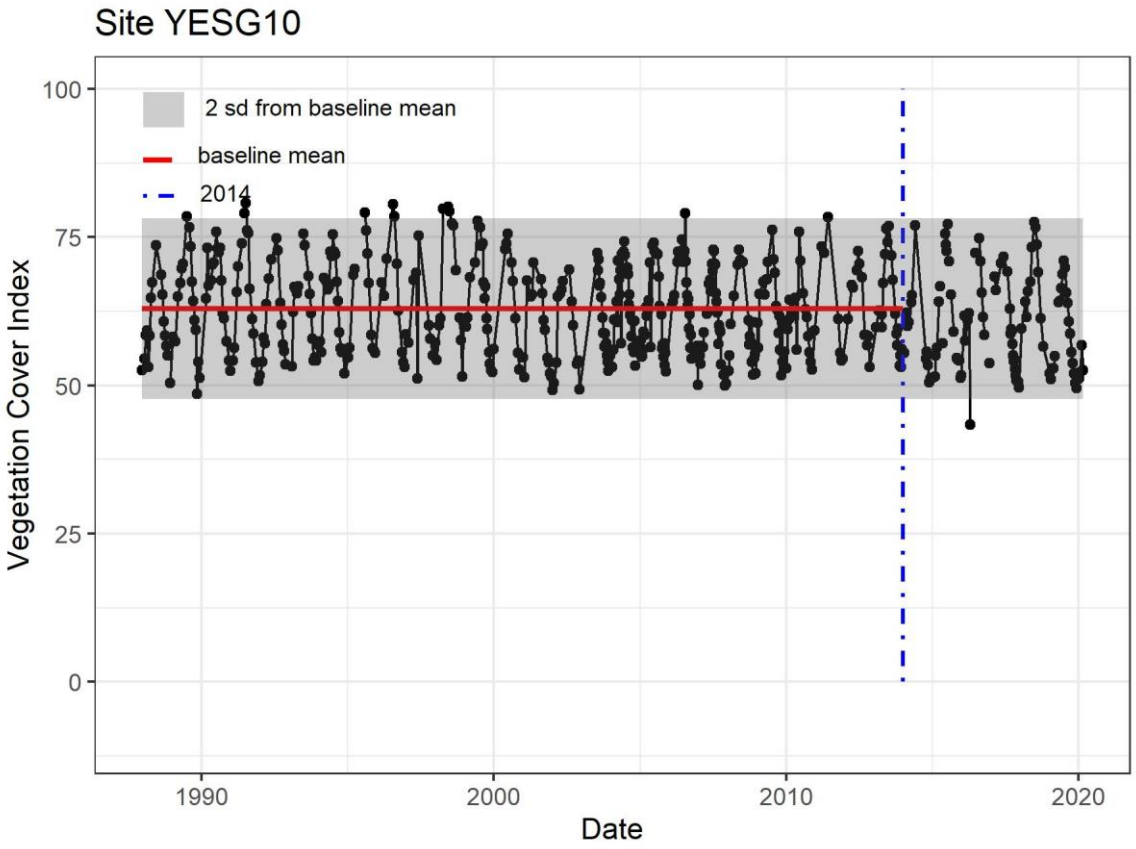

Site YESG01
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

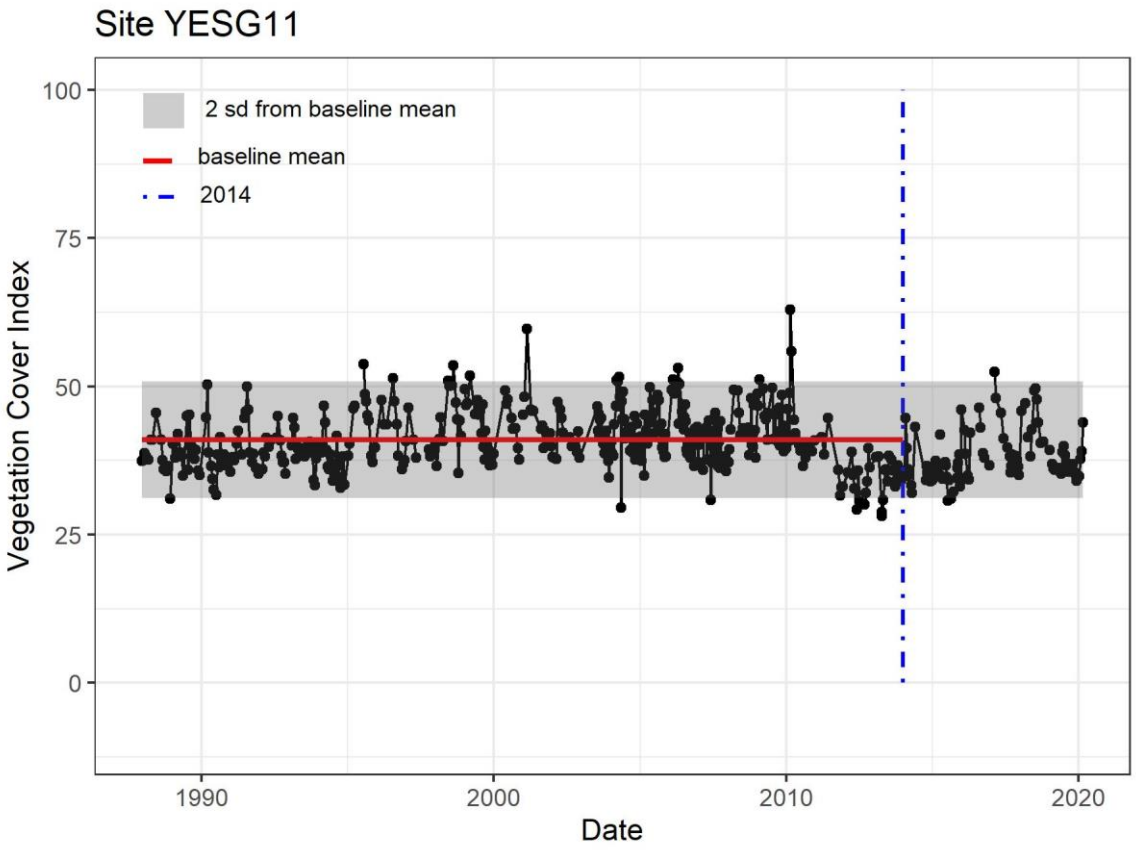

Site YESG02
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

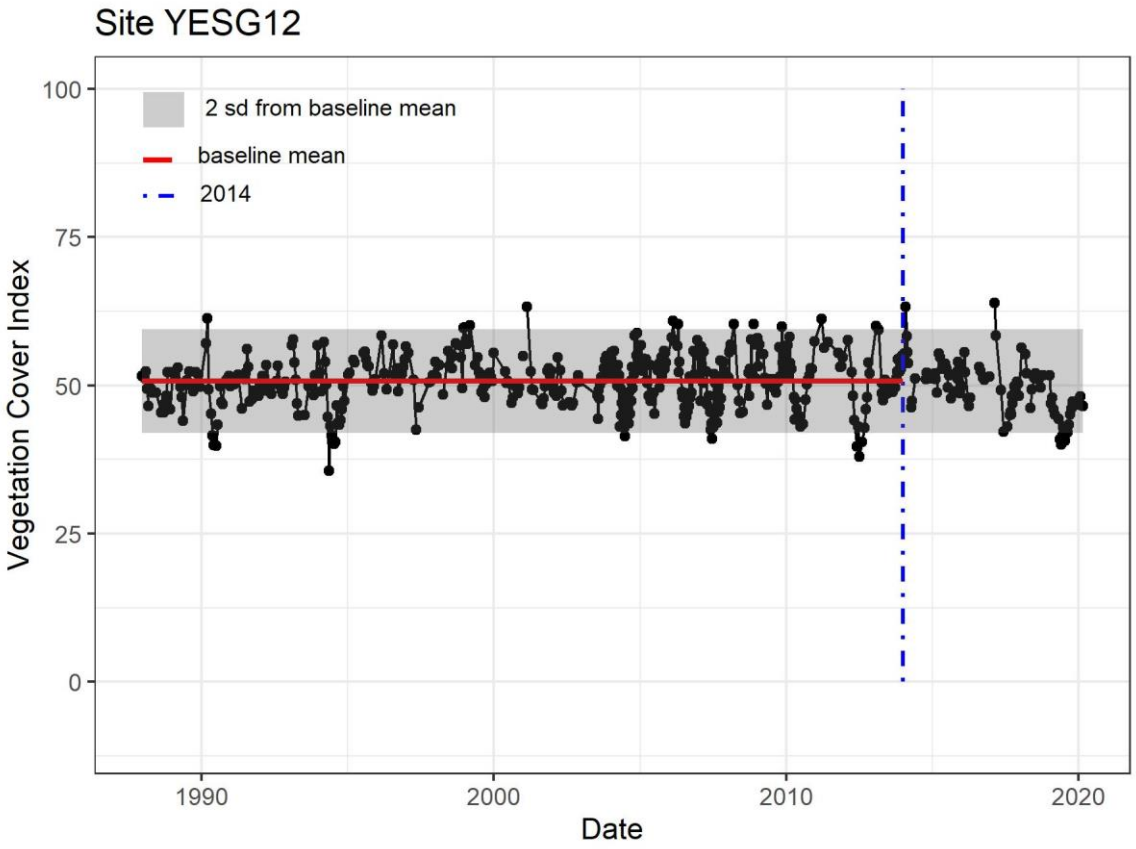

Site YESG03
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

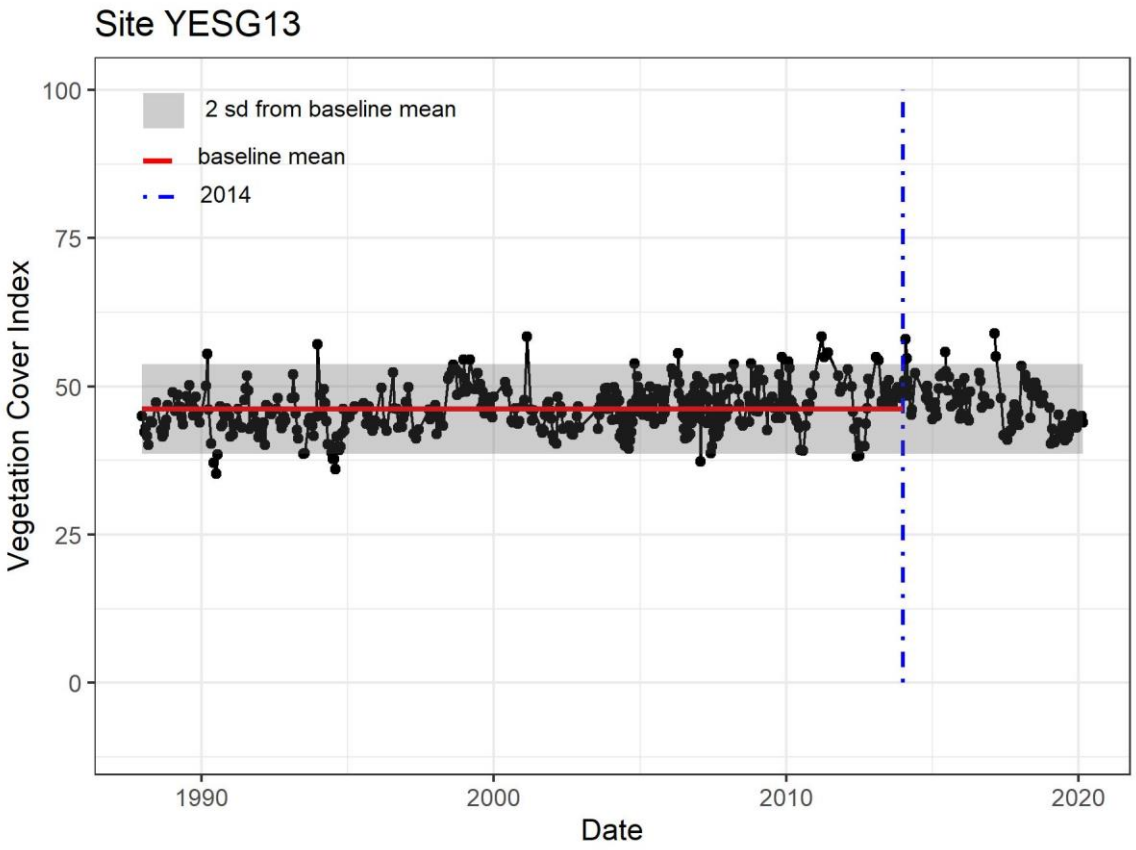

Site YESG05
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YESG07
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YESG10
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YESG11
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YESG12
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YESG13
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
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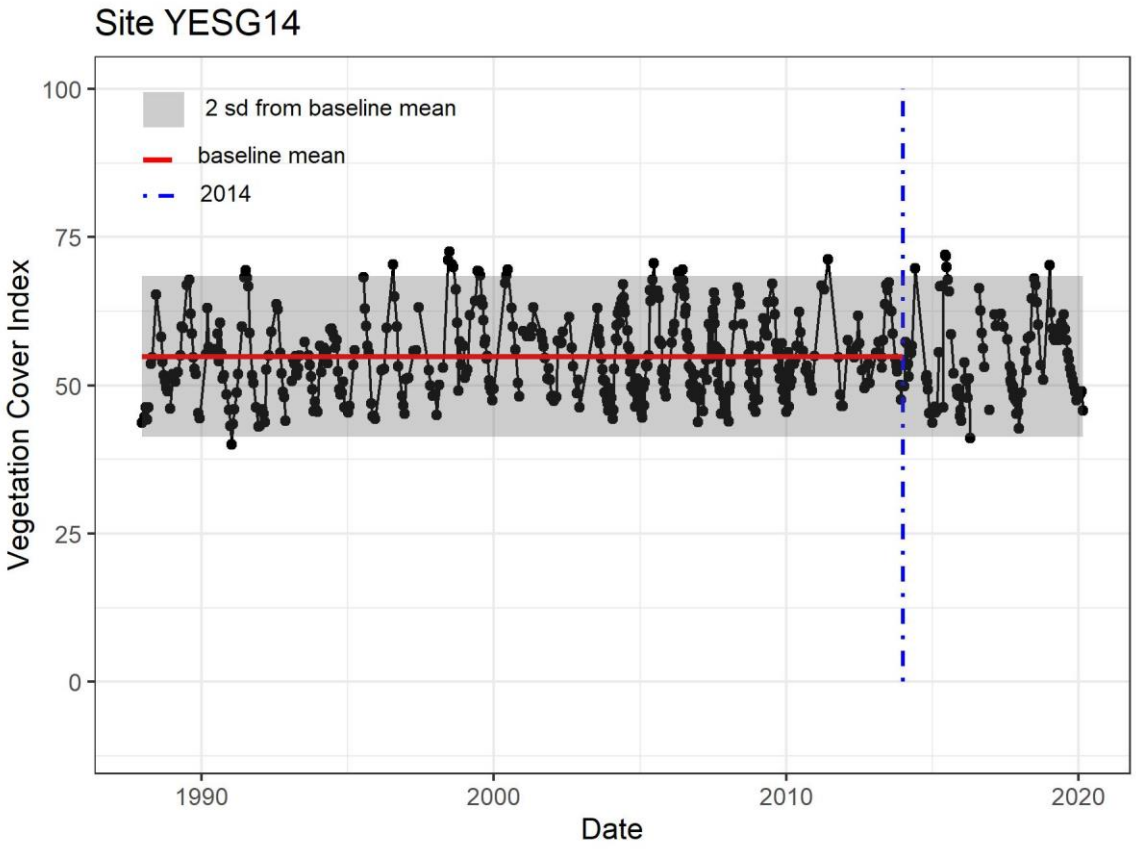
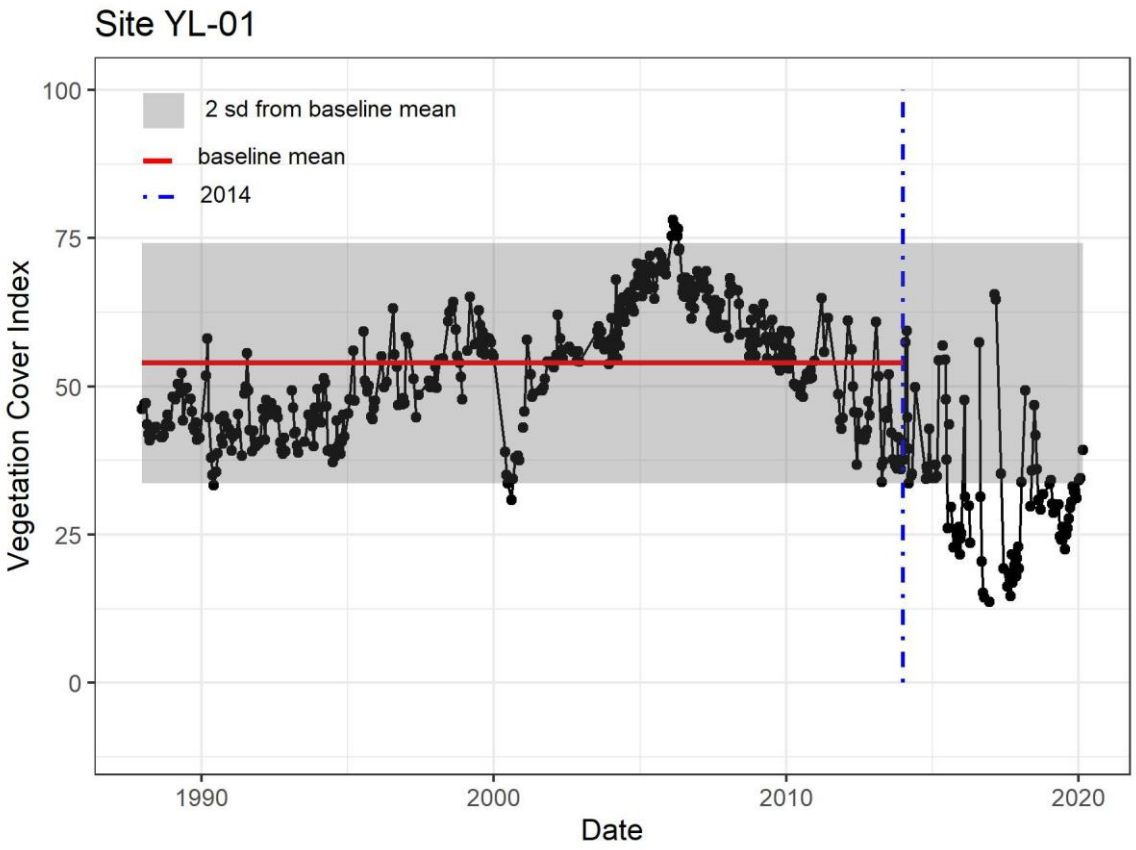
1990
2000
2010
2020
Date


Site YESG14
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YL-01
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
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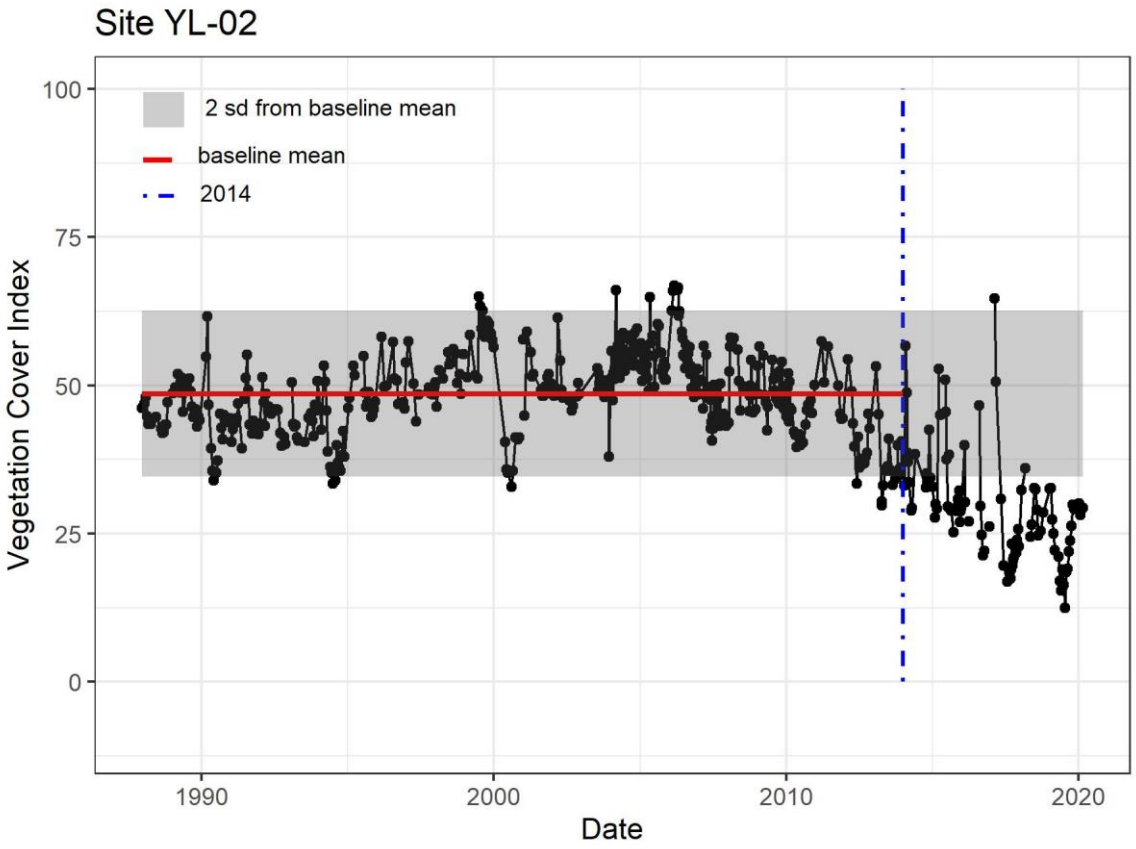
2000
2010
2020
Date


Site YL-02
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
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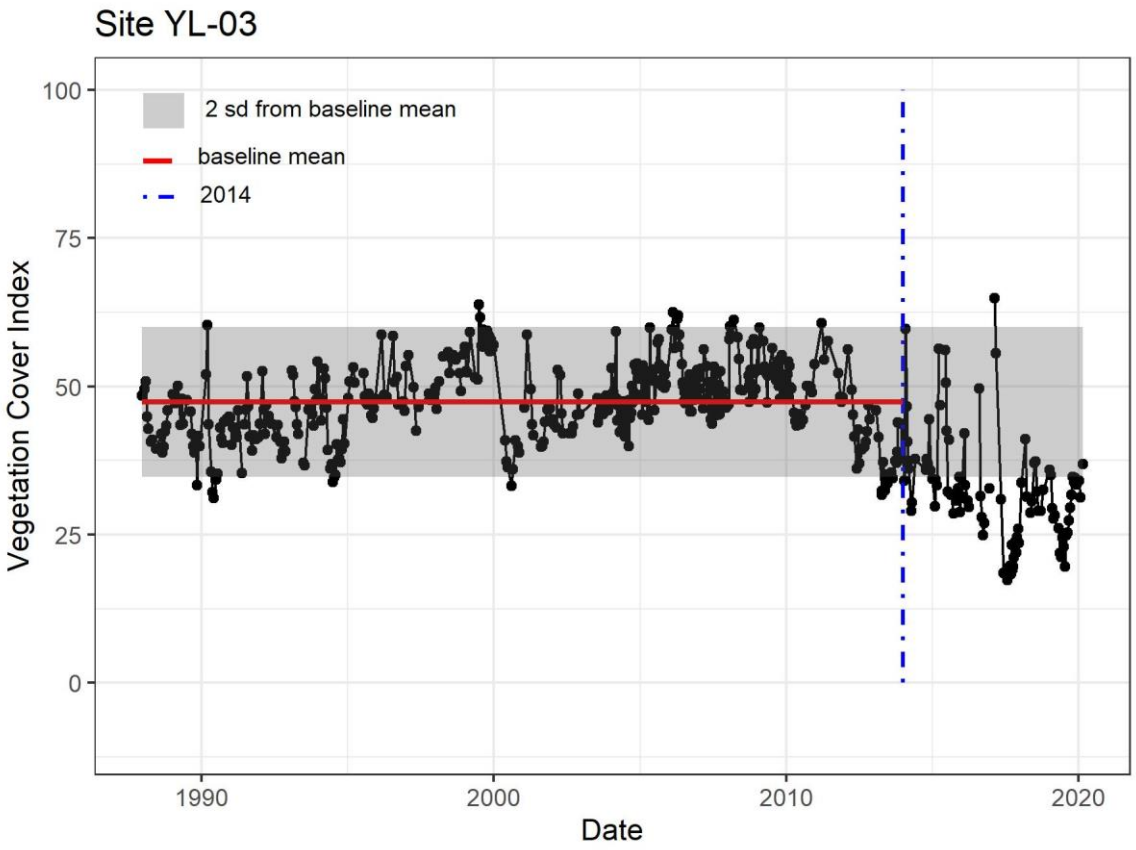
2000
2010
2020
Date


Site YL-03
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
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25
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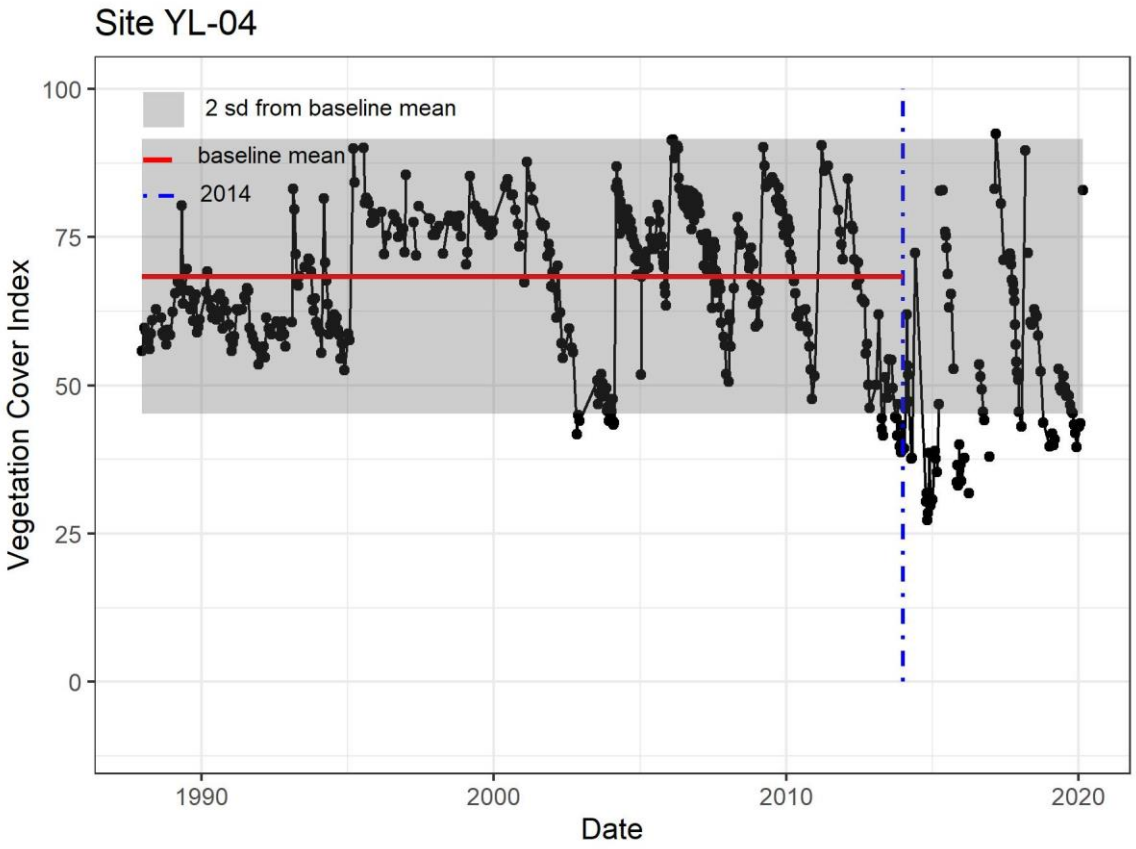
2000
2010
2020
Date


Site YL-04
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
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25
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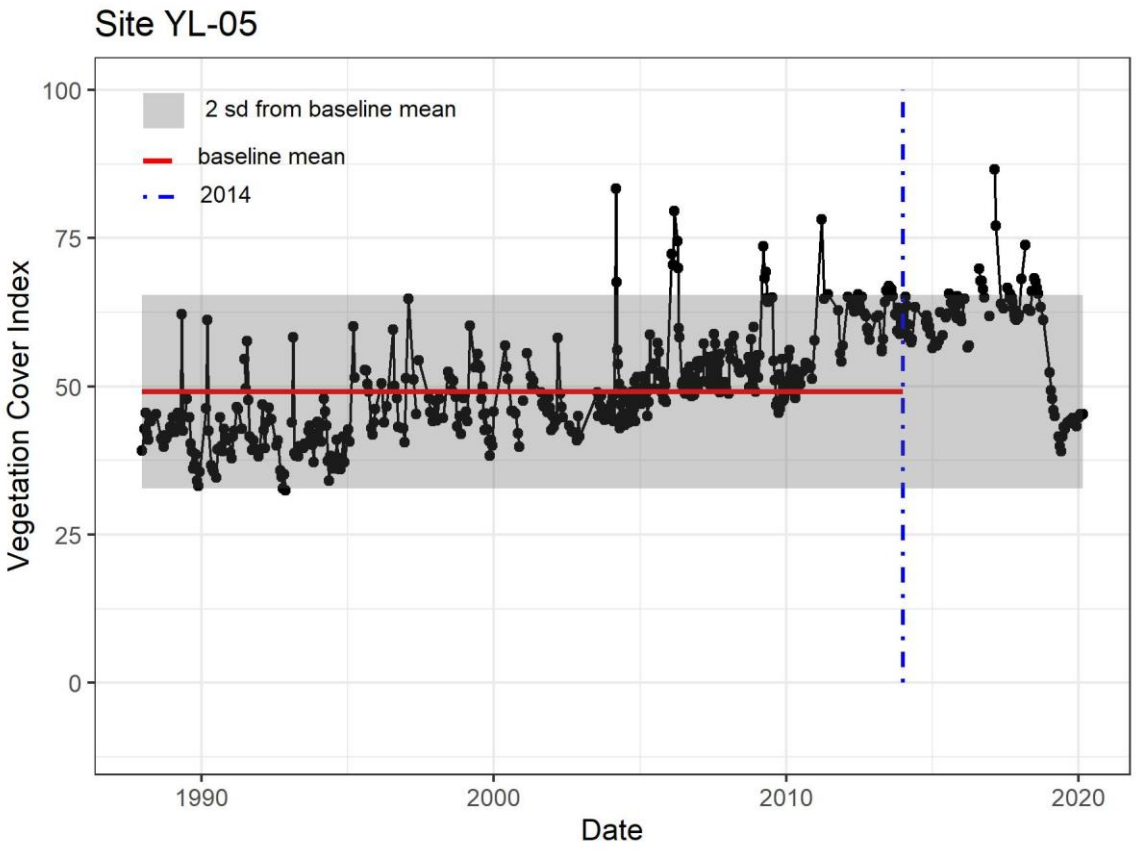
2000
2010
2020
Date


Site YL-05
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
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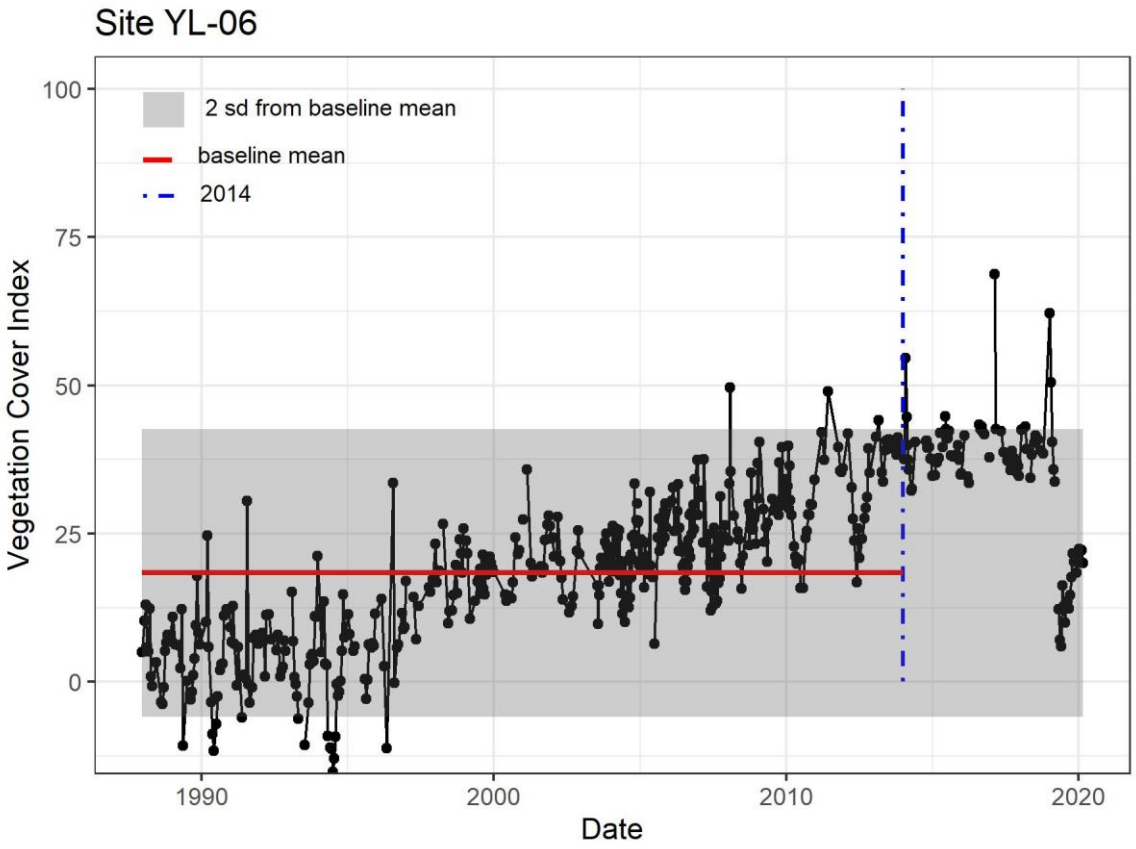
2000
2010
2020
Date


Site YL-06
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
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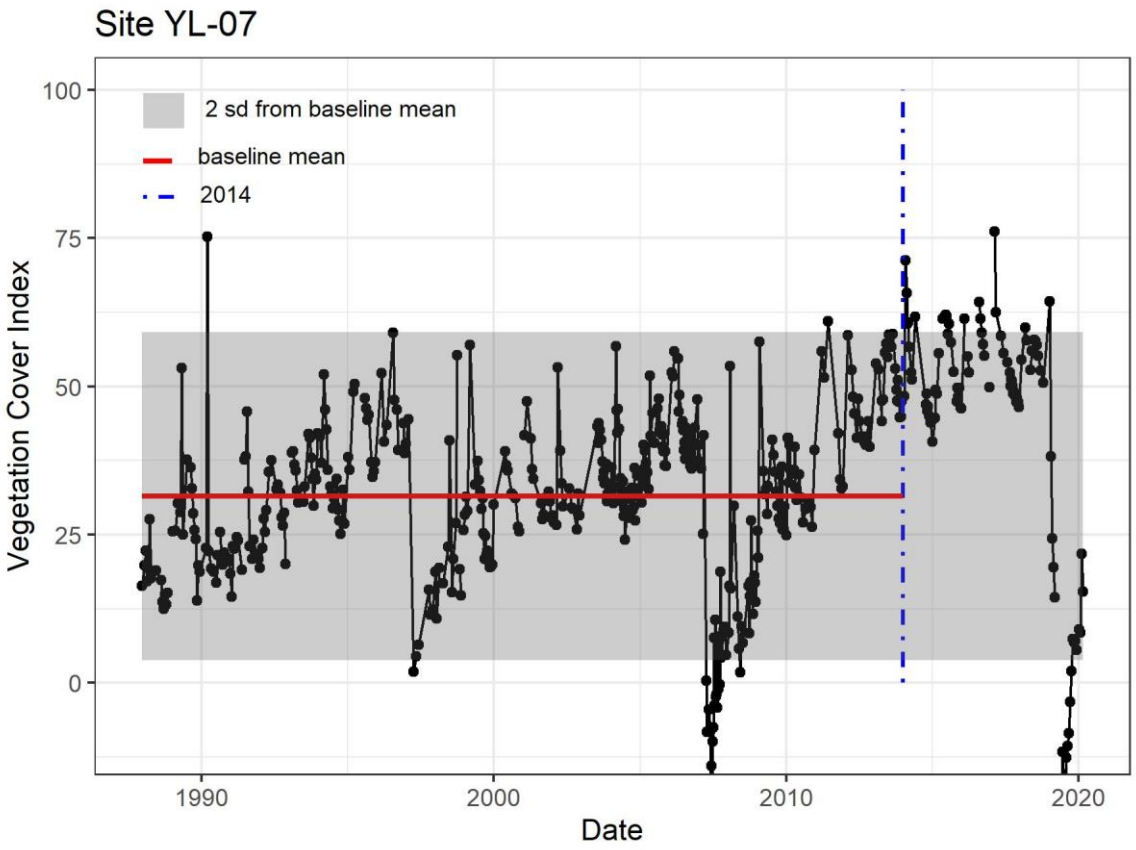
2000
2010
2020
Date


Site YL-07
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
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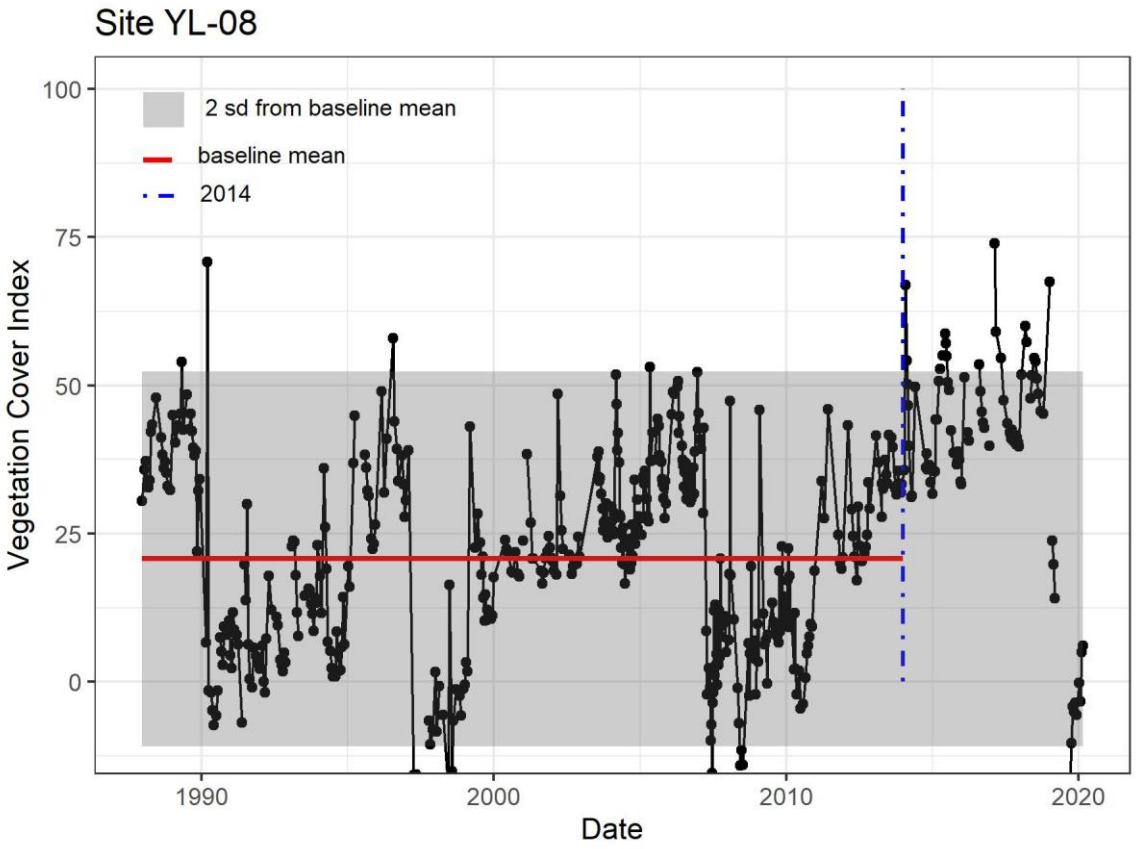
25
0
1990
2000
2010
2020
Date


Site YL-08
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
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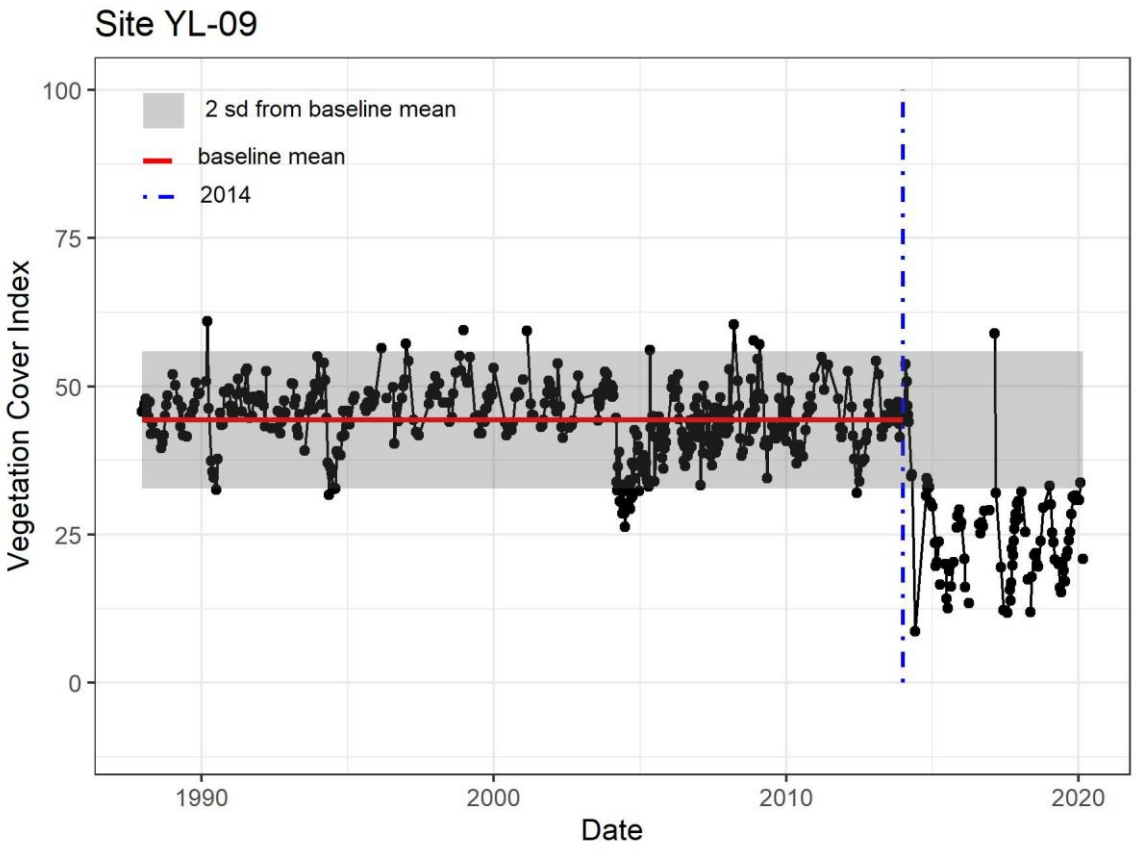
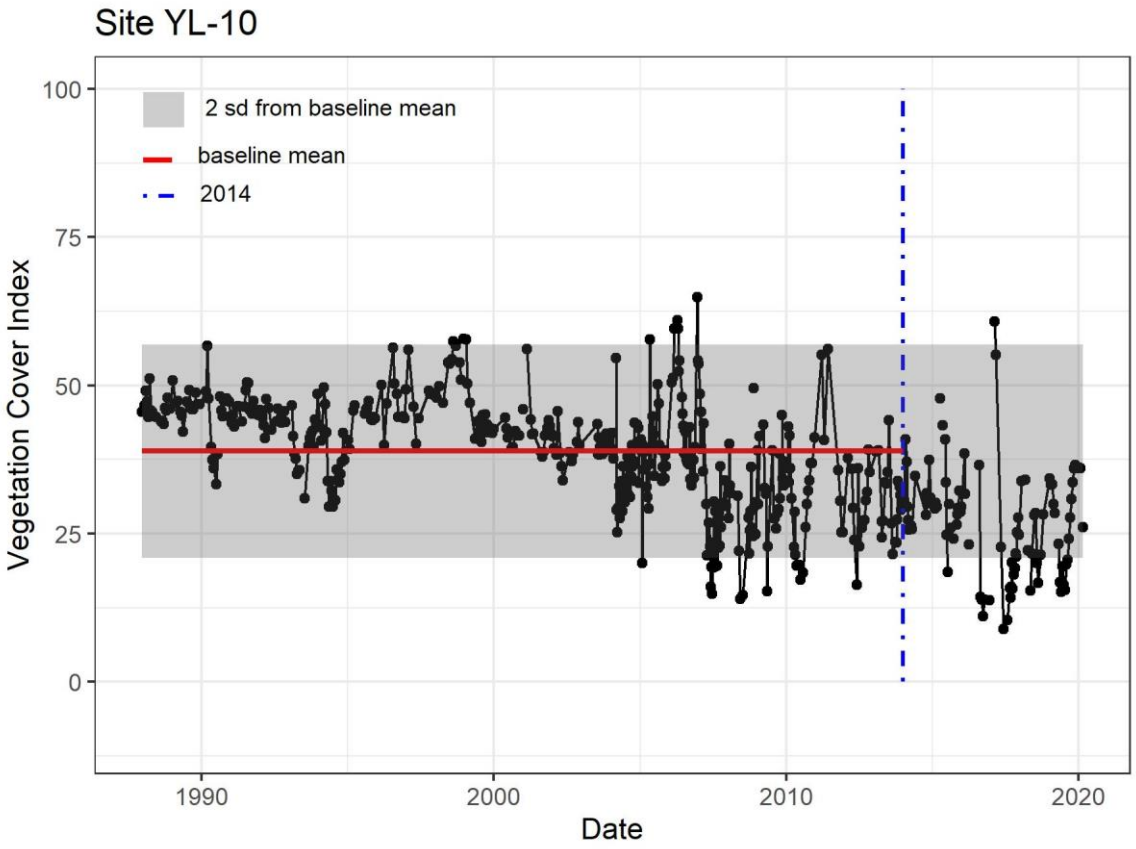
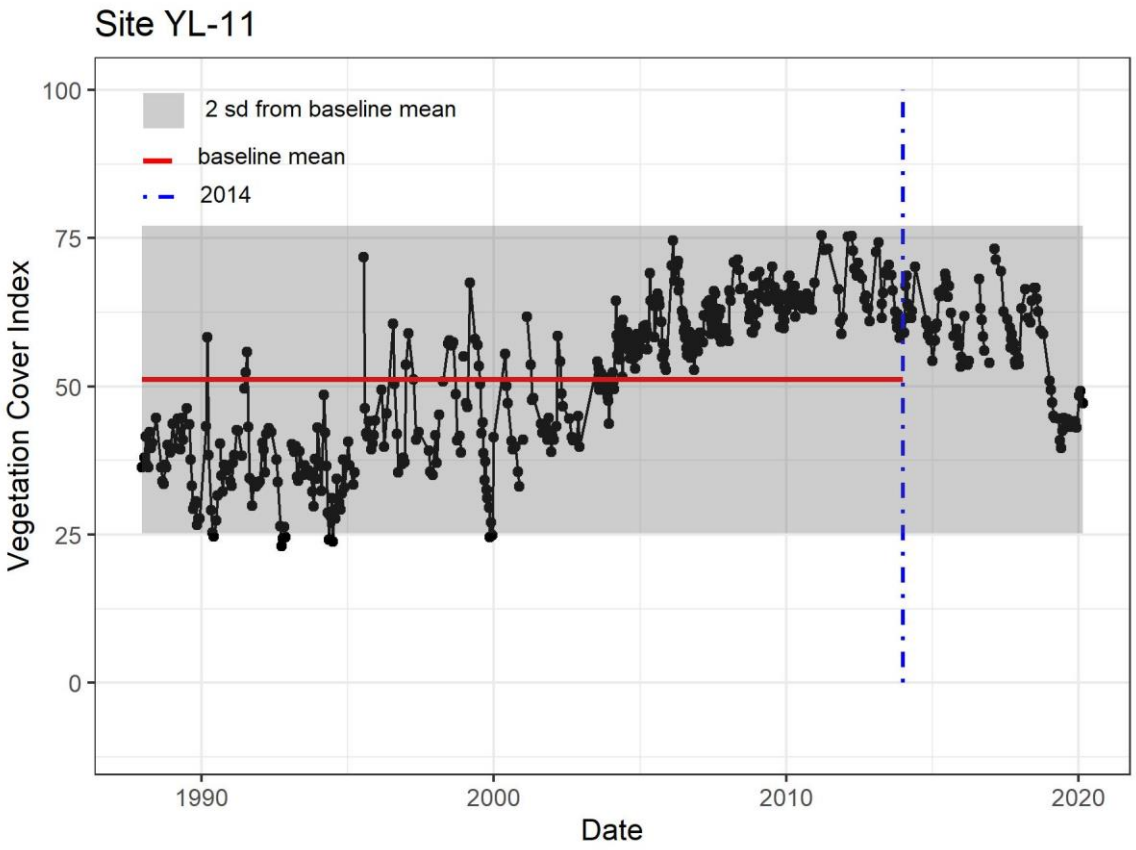
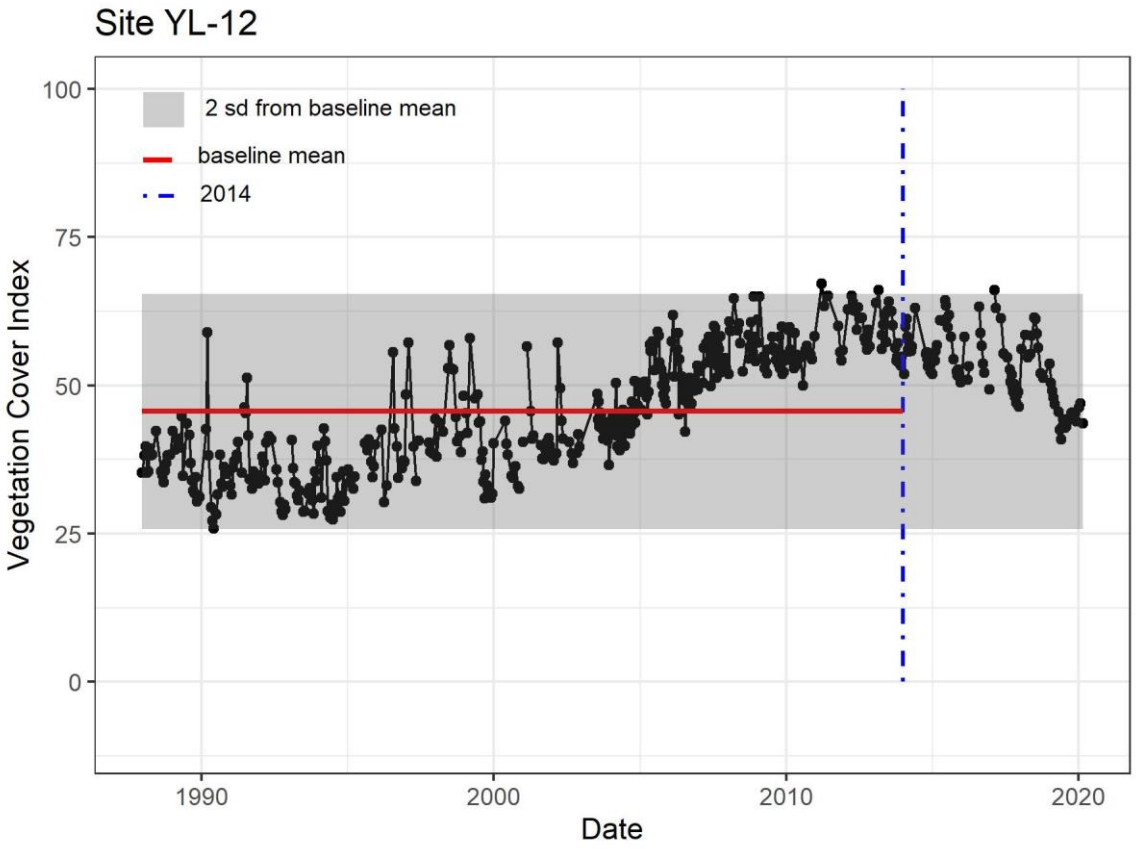
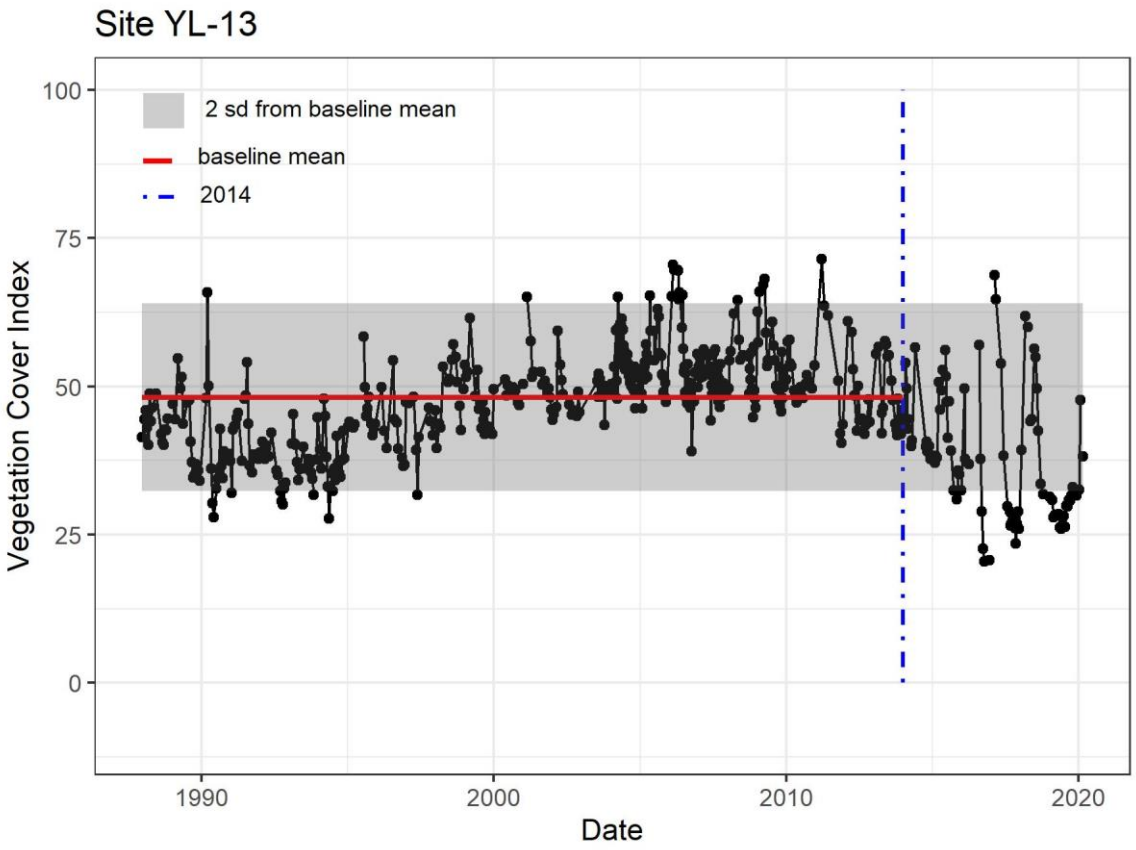
25
0
1990
2000
2010
2020
Date

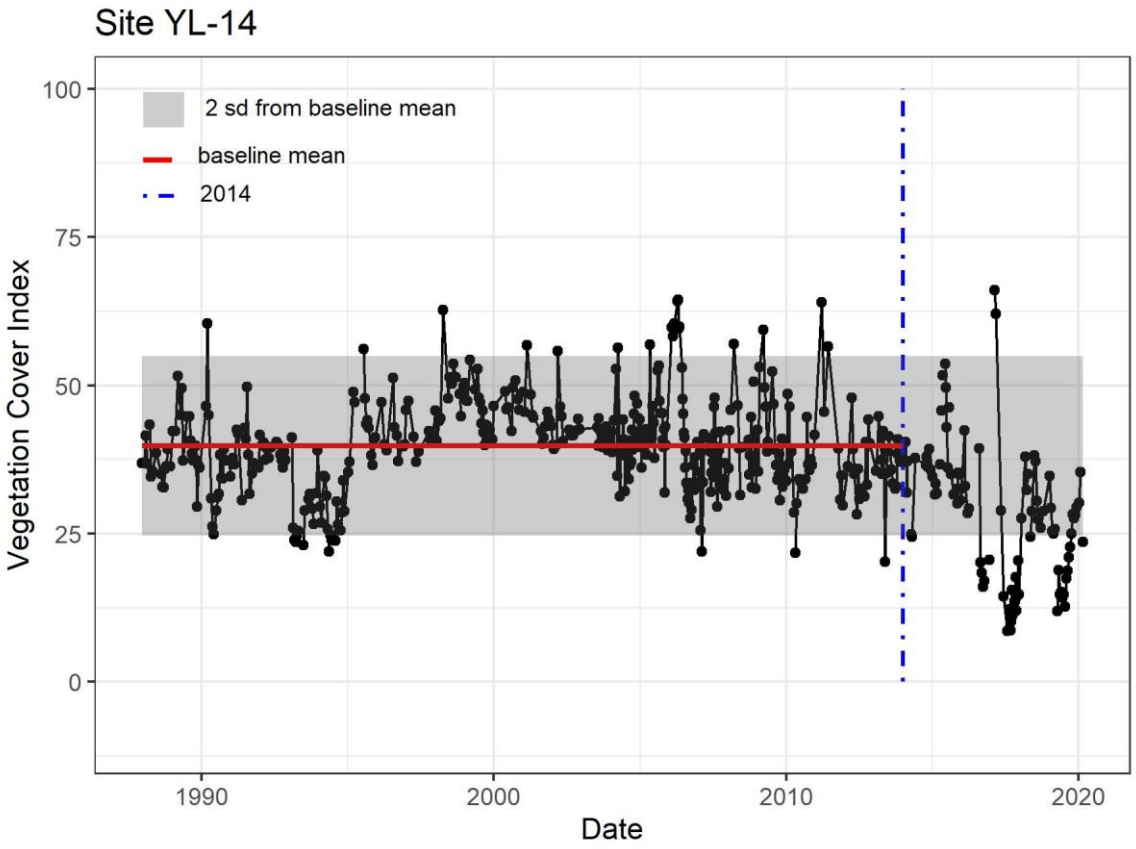

Site YL-09
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

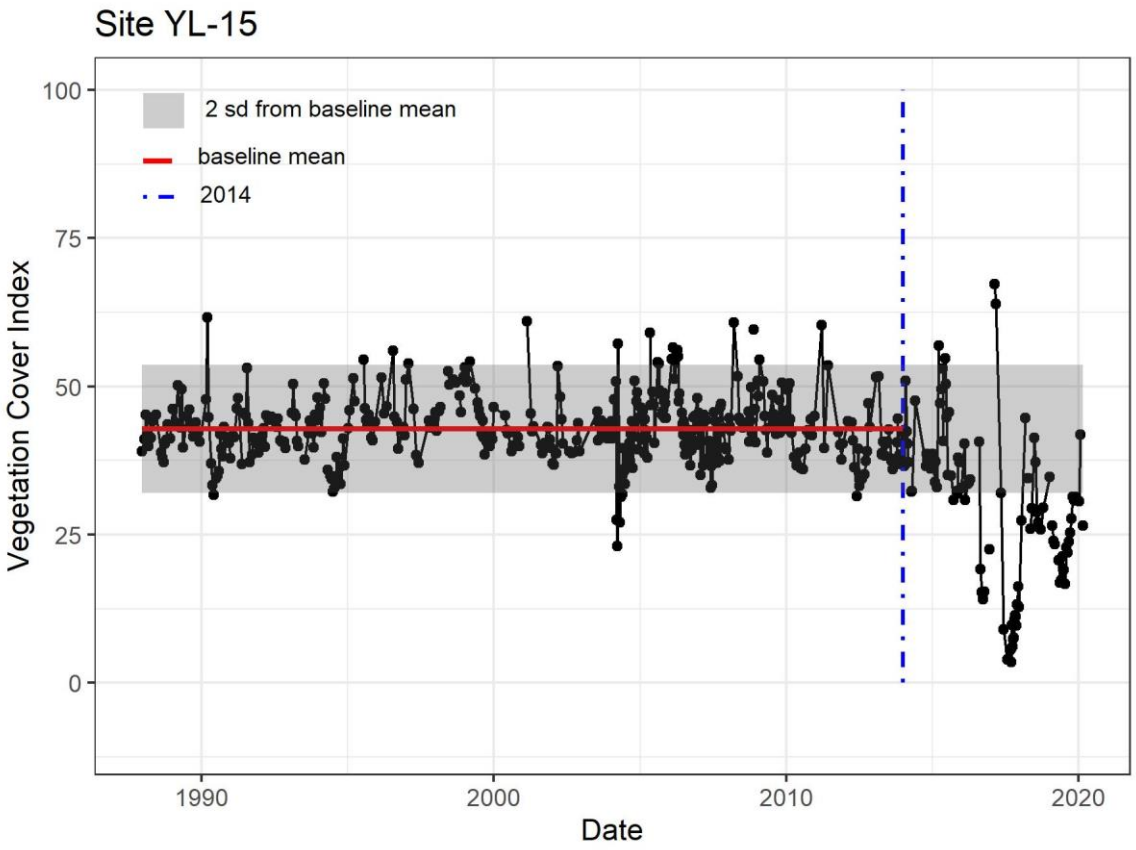

Site YL-10
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

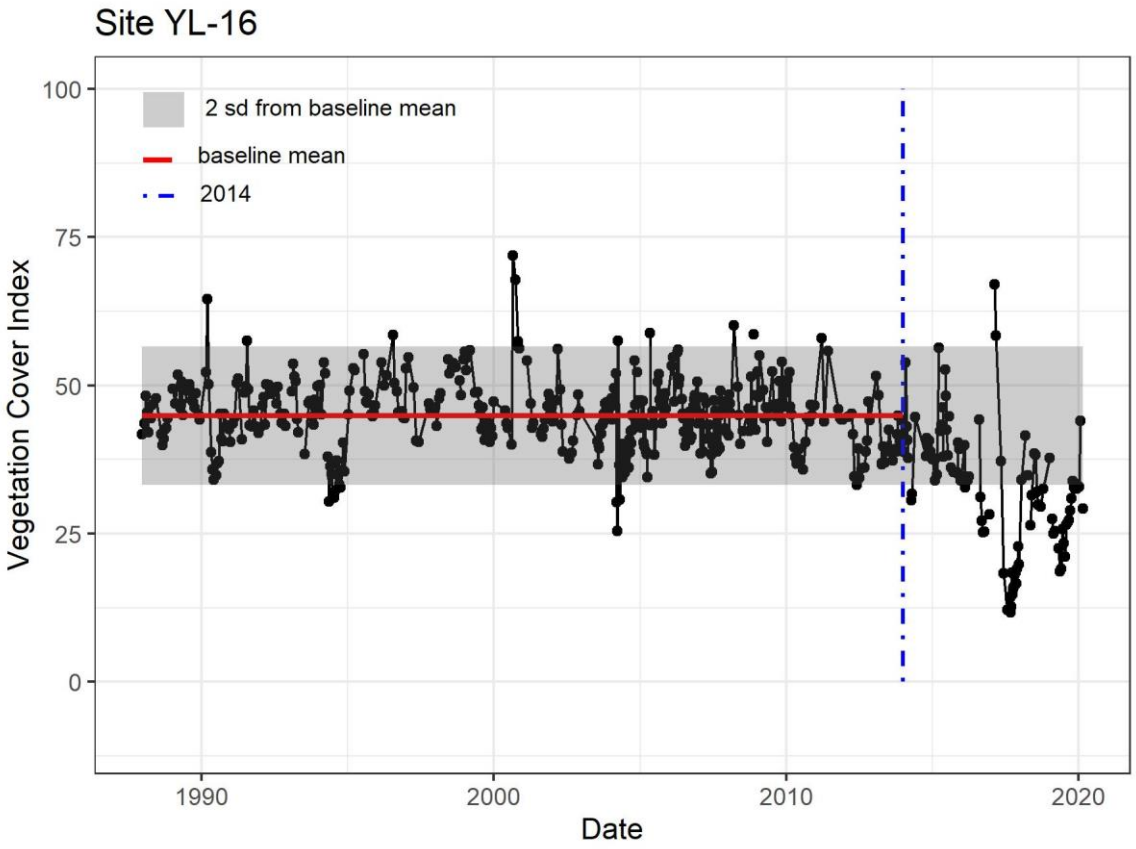

Site YL-11
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

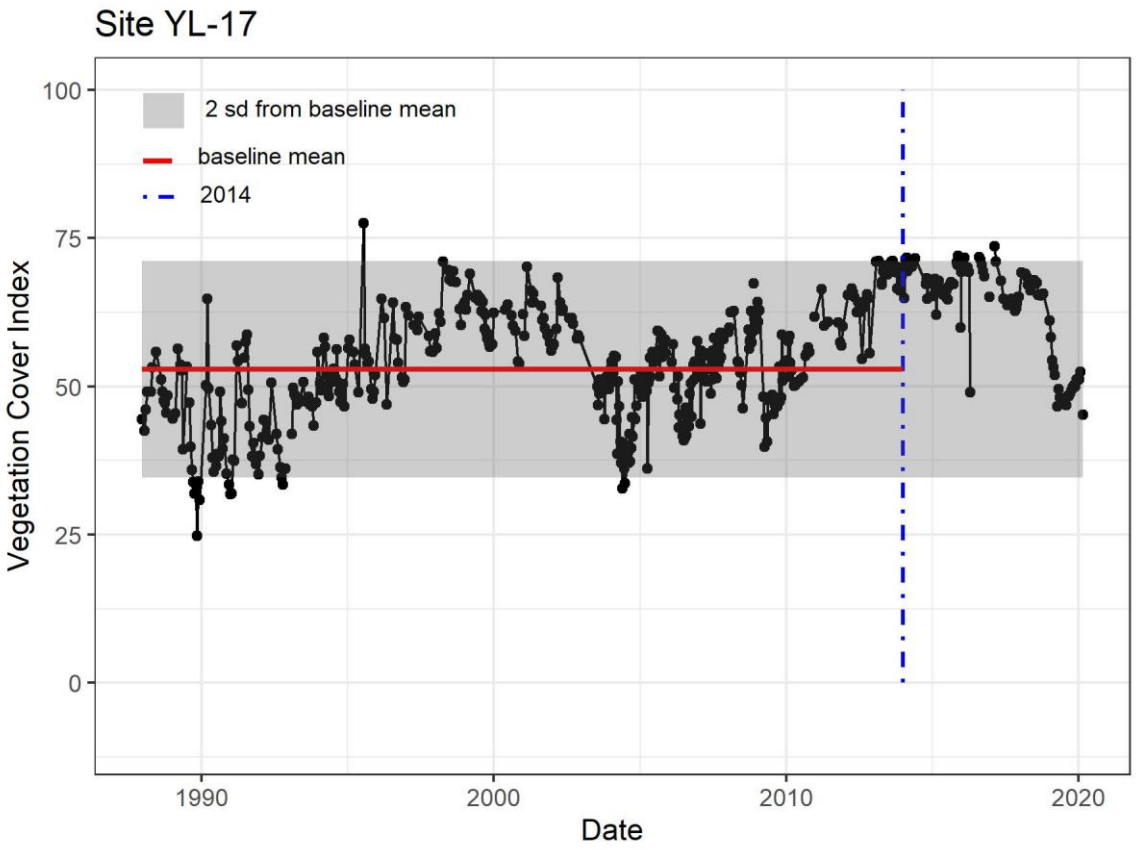

Site YL-12
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

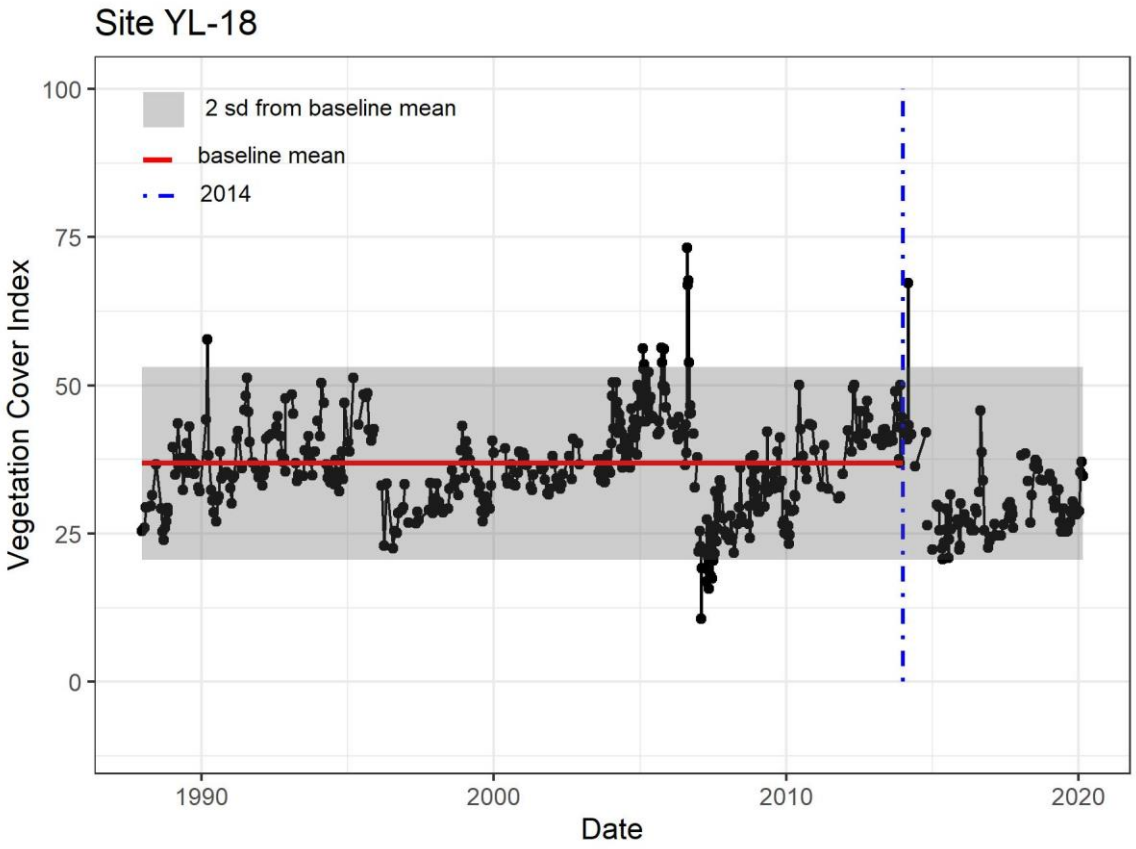

Site YL-13
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

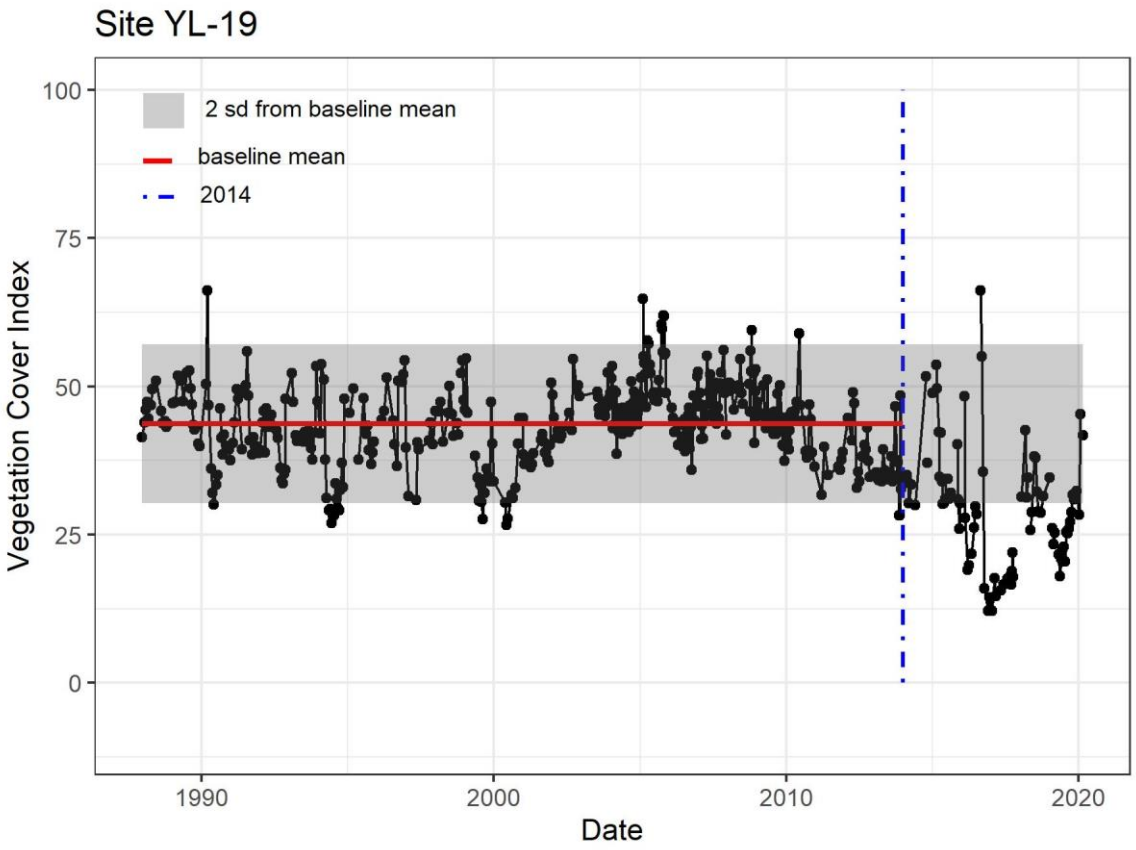

Site YL-14
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

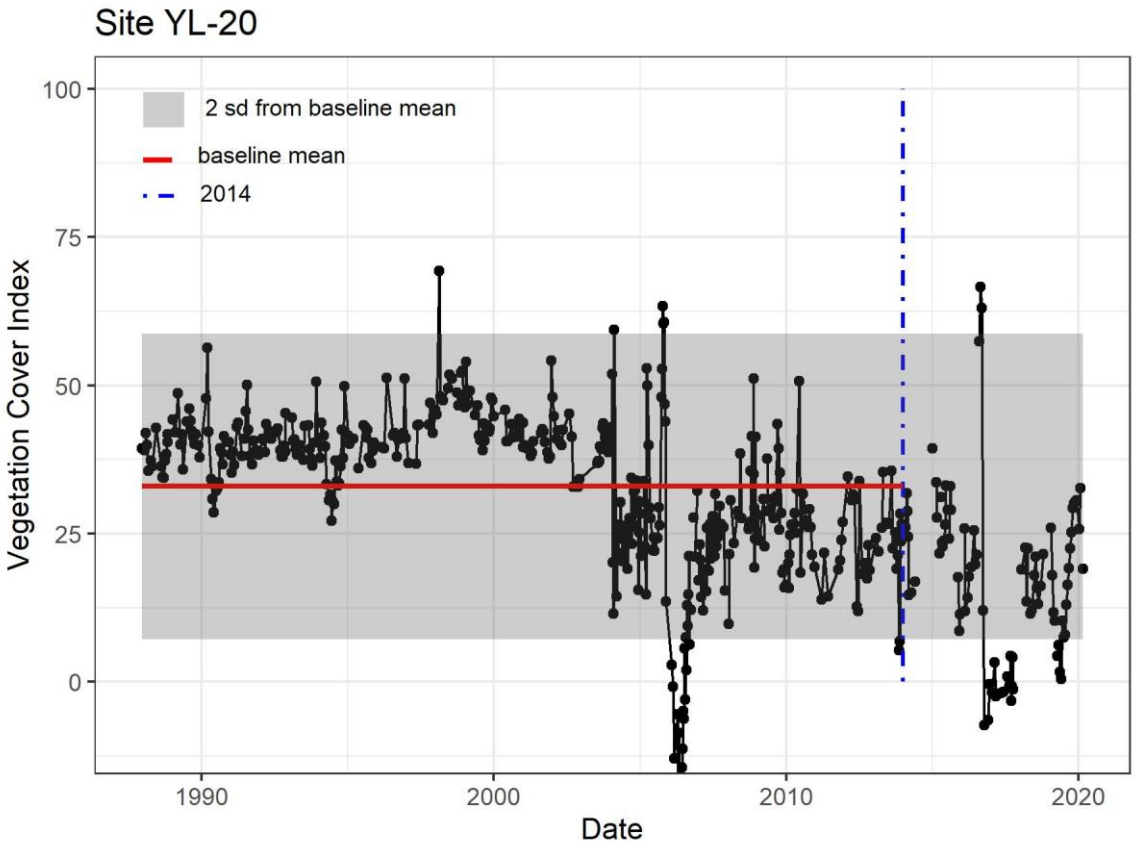

Site YL-15
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

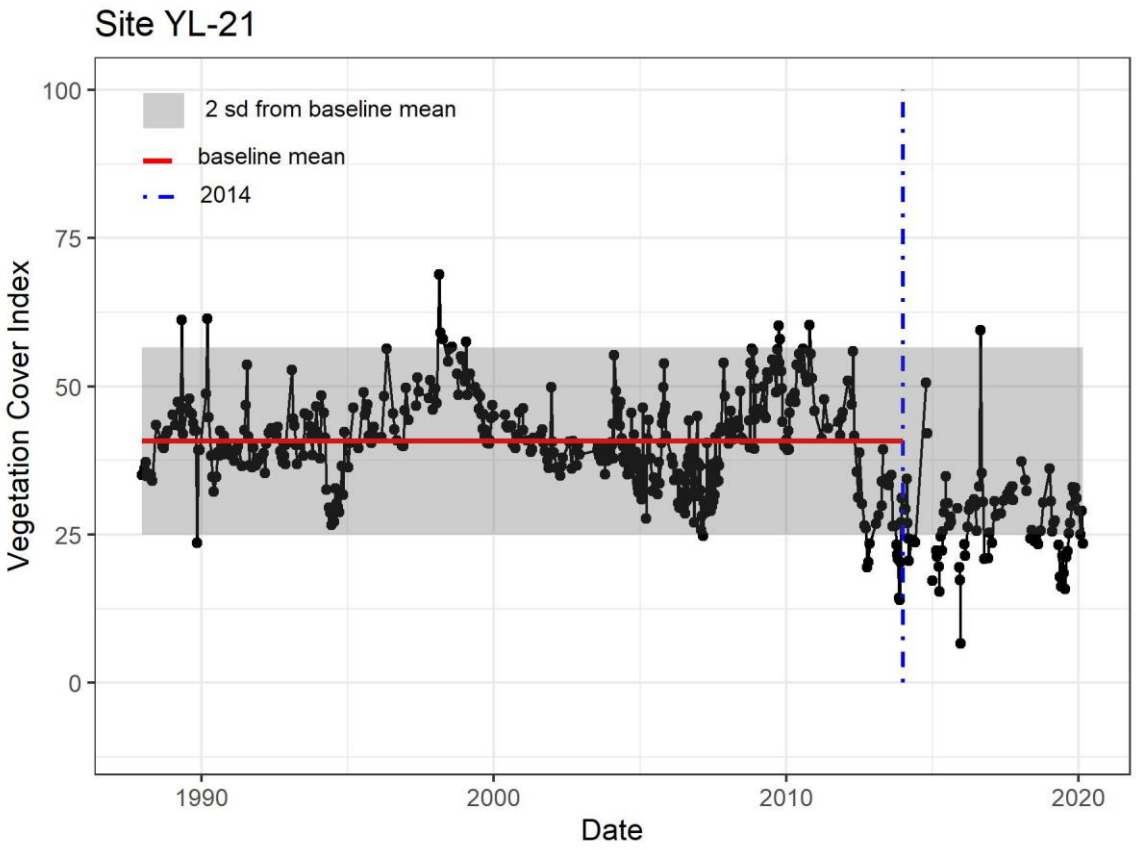

Site YL-16
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

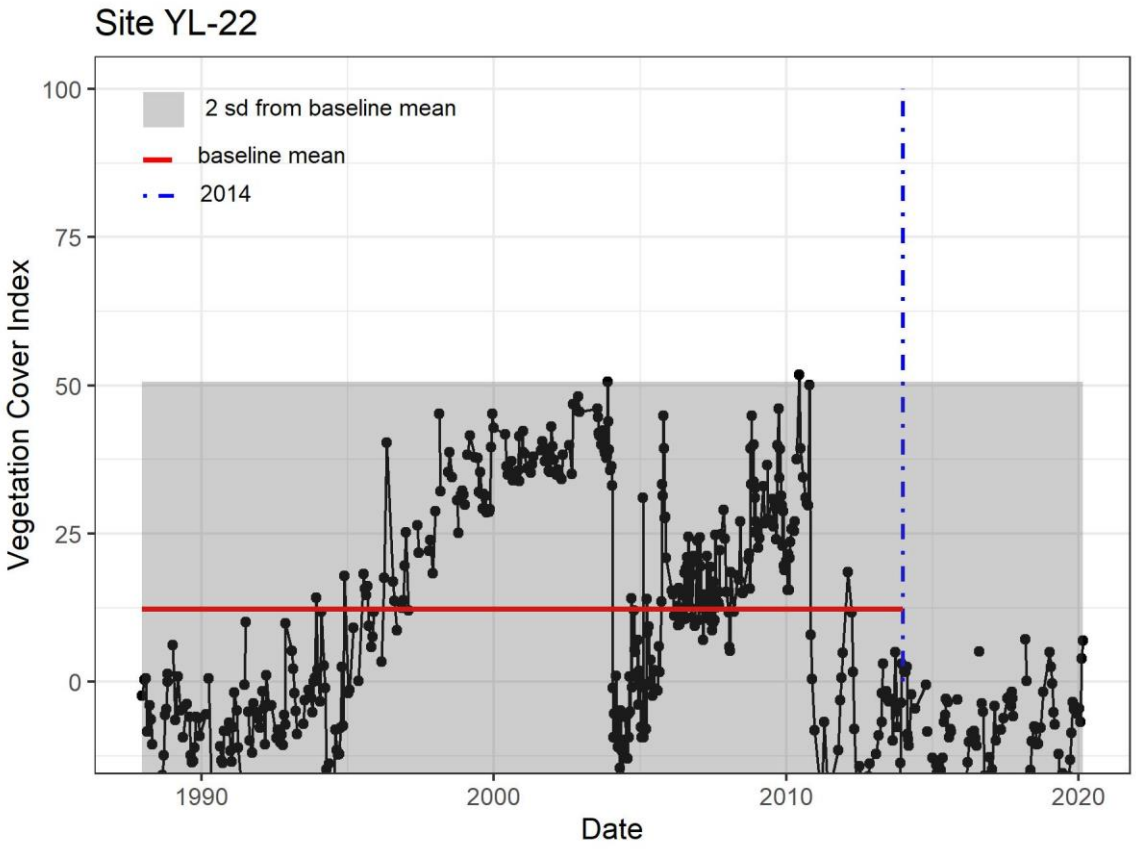

Site YL-17
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

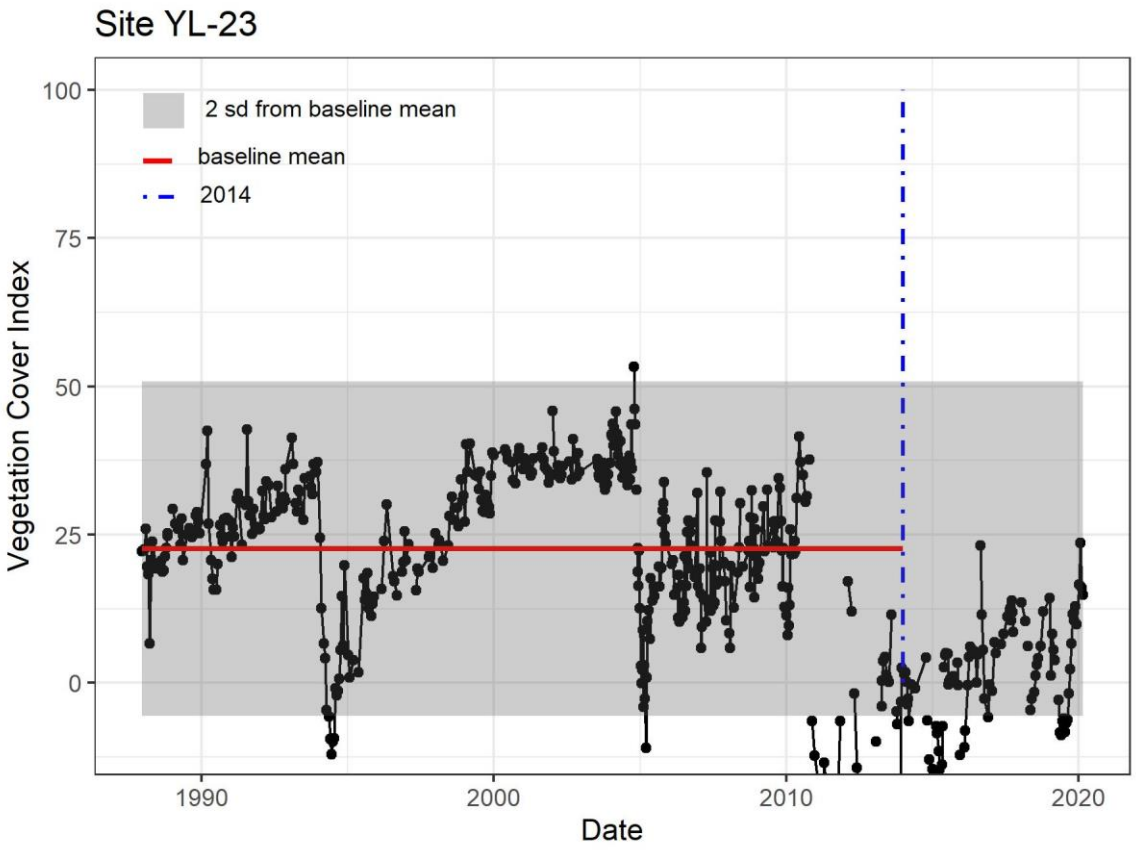

Site YL-18
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YL-19
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YL-20
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YL-21
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YL-22
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date


Site YL-23
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
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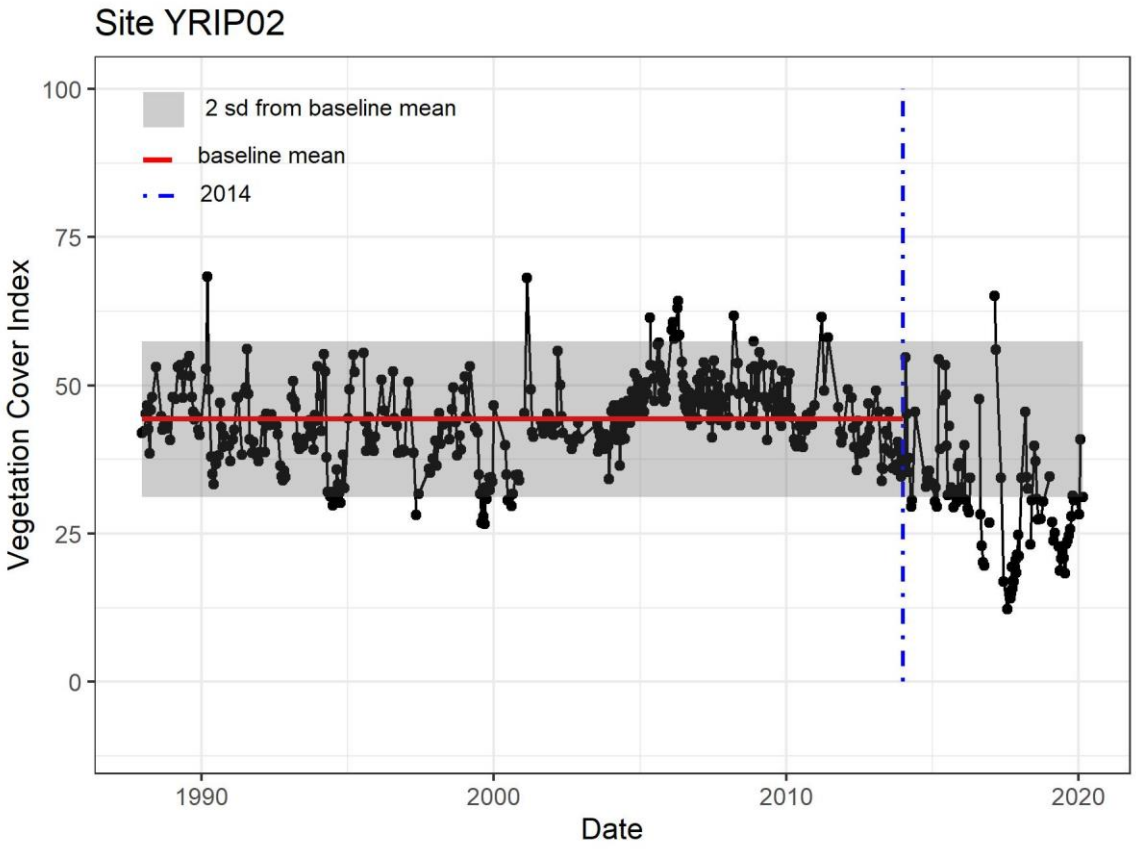
1990
2000
2010
2020
Date


Site YRIP02
2 sd from baseline mean
baseline mean
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Vegetation Cover Index
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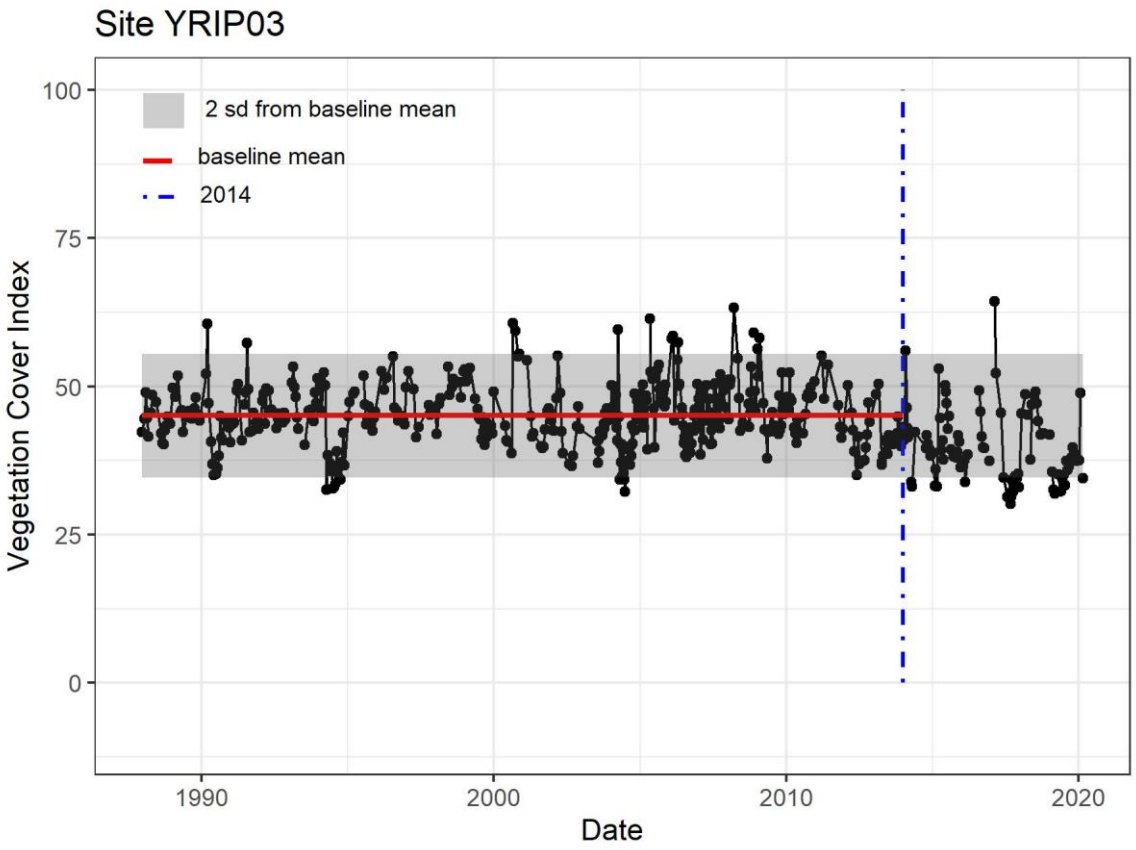
2000
2010
2020
Date


Site YRIP03
2 sd from baseline mean
baseline mean
2014
Vegetation Cover Index
100
75
50
25
0
1990
2000
2010
2020
Date

3 References

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