Spectral classification, mapping and physical habitat implications of a riparian invasion by *Tamarix ramosissima* Ledeb. in the Touws River, Klein Karoo, South Africa

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This paper investigates the invasion of a reach of the Touws River by the deciduous alien tree *Tamarix ramosissima* Ledeb. (Pink Tamarisk, Saltcedar). The objectives of the paper were to investigate the utility of a delta-normalised difference vegetation index (dNDVI) in evaluating the status, pattern and process of invasion, and to evaluate the implications of the invasion for riverscape morphodynamics and physical habitat structure and function. The spectral classification developed had an overall accuracy of 59.89%, omission error of 28.25%, and commission error of 11.86%. The classification of vegetation was used to quantify the aerial extent and pattern of invasion (currently at least 65.50% of the valley floor vegetation cover). Field observations and existing knowledge of seed dispersal mechanisms and germination constraints of the invasive tree were compared with those of the indigenous sweet thorn *Vachellia karroo*, to provide insight into invasion patterns and processes within the reach. The linear channel-flanking distribution of the invasion has the potential to alter reach hydrology and morphodynamics, which are key building blocks of physical habitat structure and function. The spectral classification approach demonstrated is relatively simple, has a strong biophysical basis in that it exploits a known, predictable and observable seasonal vegetation response that produces a clear spectral signature, and can be applied to long reaches of rivers impacted by alien vegetation invasions.

Keywords: eco-morphodynamics, invasive alien plants, non-perennial rivers, remote sensing

Introduction

EcoStatus determination for riparian vegetation (cf. Kleynhans et al. 2008) in non-perennial rivers is a challenging task (Seaman et al. 2016). High to extreme variability in flows (Puckridge et al. 1998), physico-chemistry (Day et al. 2019), and geomorphology (Jaeger et al. 2017) make it difficult to determine natural reference conditions for these driver variables (Seaman et al. 2010; Grenfell et al. 2021). Additionally, some response variables that are routinely and effectively applied in perennial rivers (e.g. macroinvertebrate-based indices) do not provide clear insight in non-perennial systems (Seaman et al. 2010; Watson and Dallas 2013). Consequently, the use of vegetation-based indices in non-perennial rivers is a more suitable approach (Seaman et al. 2010; Sabater et al. 2017), given that the vegetation is both a response variable and a flux boundary condition for physical riverscape processes through feedback effects on hydrology and morphodynamics (Dollar et al. 2007; Bertoldi et al. 2014; Gurnell 2014). Impacts of invasive alien plants (IAPs) on South Africa's water resources (Le Maitre et al. 2016), water quality (Chamier et al. 2012), fluvial geomorphology (Rowntree 1991), and biodiversity and ecosystem service provision (van Wilgen et al. 2008) are well established. As such, the status, pattern and process of vegetation invasions could provide clear insight into riverscape EcoStatus and trajectories of change.

However, operationalising such insight into an index for EcoStatus determination first requires an understanding of the current distribution of an IAP, and the mechanisms by which it invades an environment (e.g. Tickner et al. 2001; Richardson et al. 2007). It is therefore fortuitous that recent advances in remote sensing and geospatial analysis and the advent of new sensor platforms, such as Sentinel 2, are driving steady improvements in our ability to identify and map the distribution of IAPs with increasing accuracy (e.g. Mtengwana et al. 2020), and to model the potential future spread of invasions (Mtengwana et al. 2021). Such understanding is critical in evaluating the effects of riparian invasions on riverscape morphodynamics and physical habitat structure and function to enhance EcoStatus determination (Grenfell et al. 2021). The objectives of this paper are to i) investigate the utility of a delta normalised difference vegetation index (dNDVI) in evaluating the status, pattern and process of invasion of a reach of the Touws River by *Tamarix ramosissima* Ledeb. (Pink Tamarisk, Saltcedar), and ii) consider the implications of the invasion for riverscape (channel-floodplain) physical habitat dynamics.

Tamarix ramosissima is a salt-tolerant, facultative phreatophyte that favours river corridors, and becomes established where the depth to groundwater is 1–5 m (CABI 2019a). The flowers of the plant produce large quantities of fine, wind or water dispersed seed, and the plant is

considered particularly effective at invading riparian areas following the recession of floodwaters (CABI 2019a). It was likely introduced to South Africa as an ornamental garden plant in the 1990s to 2000s (CABI 2019a), and was reported as invasive in rivers of the Klein Karoo by Mucina et al. (2006). The plant was listed in 2002 as a Category 1 invader through the Conservation of Agricultural Resources Act (43/1983, as amended), and is thought to out-compete native species, reduce streamflow, and draw on groundwater resources (Le Maitre et al. 2007). *T. ramosissima* was listed as one of eight IAPs in the Nama and Succulent Karoo Biomes considered important in terms of prioritising quaternary catchments for alien

plant control, with a relative importance rank of 6/8 (based on criteria related to current invasion extent, biodiversity and ecosystem service value of the invaded area, control potential, and control benefits in terms of water resources and job creation; Forsyth et al. 2012).

Materials and methods

Study area
The study site centres on a large pool within a reach of the Touws River near the town of Plathuis in the Klein Karoo (Figure 1). The Touws River is a mixed-load (sand-gravel-cobble), mixed bedrock-alluvial non-perennial river with a
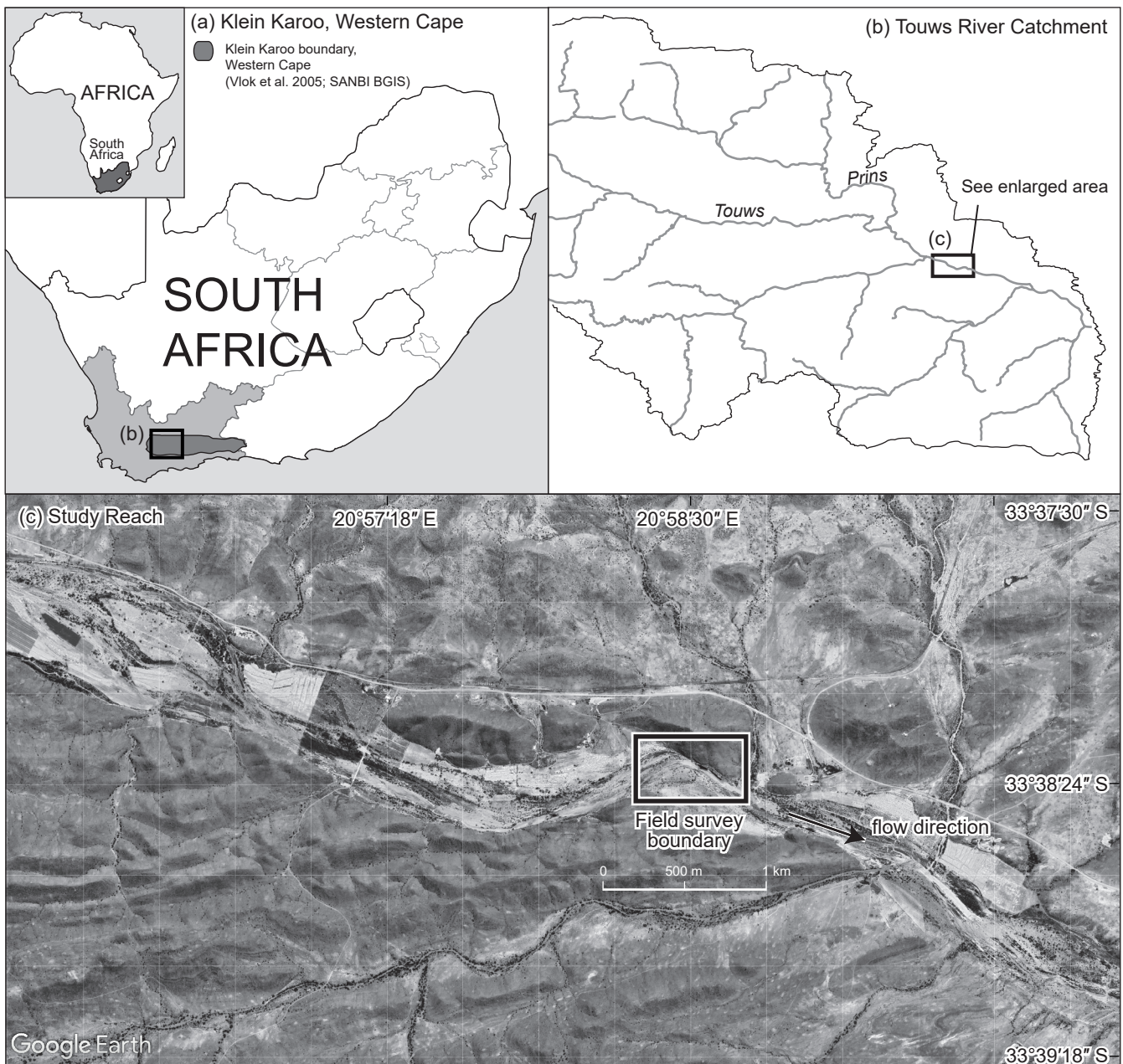
Figure 1: Regional setting of the study reach of the Touws River, within the Klein Karoo, Western Cape Province, South Africa

highly variable flow regime. The mean annual discharge of the river at Plathuis is ~0.73 m³ s⁻¹, whereas the range in mean daily flow is 0 to 1 515 m³ s⁻¹ (maximum mean daily flow recorded during the March 2003 flood peak; Grenfell et al. 2021). Fluctuations in pool water level are driven by a combination of episodic river flows, and local rainfall and runoff events, supplemented by a limited contribution from local Adolphspoort Formation shale-based saline groundwater discharge (see Grenfell et al. 2021 for a full description of Touws River form and processes).

Plathuis has a mean annual precipitation (MAP) of 155 mm y⁻¹ (Schulze and Lynch 2007), a mean annual potential A-Pan evaporation (PE) of 2 253.2 mm y⁻¹ (Schulze and Maharaj 2007), and a UNEP (1997) Aridity Index of 0.07 (arid). The mean annual temperature is 17.9 °C, with summer temperatures sometimes exceeding 40 °C (Mucina et al. 2006). The vegetation of the reach comprises riverine thicket (locally relatively sparse) of unit AZi 8 (Muscadel Riviere), which is dominated by *Vachellia karroo* and *Caroxylon aphyllum*, and is variably invaded by *Tamarix ramosissima* Ledeb. (Mucina et al. 2006). Muscadel Riviere vegetation is endangered, with more than 60% already transformed through cultivation and road building (Mucina et al. 2006).

The broader Klein Karoo region (Figure 1c) is water-scarce, with a combined mean annual runoff for the Touws, Gamka and Olifants rivers of 540 Mm³ y⁻¹, and combined groundwater recharge for the catchments of these rivers of ~257 Mm³ y⁻¹ (Le Maitre et al. 2009). Groundwater recharge is considered to vary across the region with the proportion of representation of Table Mountain Group (TMG) sandstone-dominated lithologies (Le Maitre et al. 2009). Groundwater discharge contributions to rivers are typically low, especially where riverbeds are superimposed upon Bokkeveld Group shale lithologies, but can be locally important where rivers intersect the TMG relief (Le Maitre et al. 2009).

Human modifications to landscape-scale water, sediment and nutrient fluxes in the Klein Karoo were reviewed by Le Maitre et al. (2007). Significant impacts in the context of the current study include land degradation associated with overgrazing, which can increase the transfer of sediment to the riverscape, and the widespread (and increasing) practice of runoff harvesting and flood irrigation, which together with land degradation can increase the transfer of nutrients and salts to the riverscape (DWAF 2003; Le Maitre et al. 2007). *Tamarix ramosissima* is explicitly identified by Le Maitre et al. (2007) as a potential modifier of riparian water balances through enhanced transpiration, and of sediment dispersal and accumulation patterns through enhanced sedimentation rates. This is especially the case in shale-bed environments with high natural background salinity, and environments subjected to elevated salt loads through the activities described above (Le Maitre et al. 2007; Day et al. 2019).

Field vegetation survey

A differential GPS with subdecimetre accuracy in *x*, *y*, and *z* fields was used to record location points of cover-dominant plant species and bare sediment, across an approximately 0.12 km² (12 ha) area of the Touws riverscape. The intention of the survey was not to develop a comprehensive species list, but rather to mark locations of individuals (e.g. isolated thorn trees) and stands (e.g. patches of a single species) of the dominant vegetation cover of the valley floor, to serve as a reference dataset for geospatial classification. The survey was conducted partly along transects oriented perpendicular to the valley thalweg, with additional cover points tracking
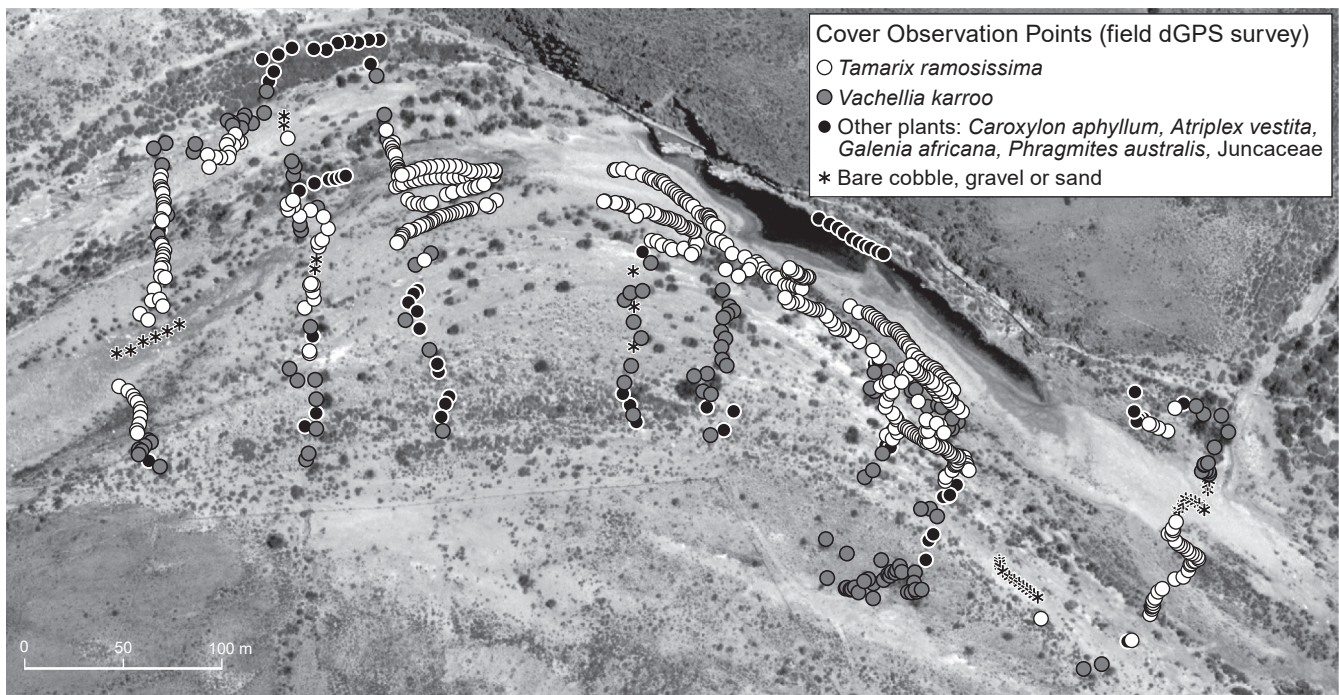
Figure 2: dGPS point cover sample observations of vegetation and bare sediment across the field survey area

the observable distribution of the two dominant tree species within the reach (*Tamarix ramosissima* and *Vachellia karroo*) (Figure 2).

A total of 738 discrete cover observations were sampled for bare sediment (38), *Tamarix ramosissima* (489), *Vachellia karroo* (134), *Caroxylon aphyllum* (37), *Atriplex vestita* (9), *Galenia africana* (10), *Phragmites australis* (15), and Juncaceae (6). The trees *T. ramosissima* and *V. karroo* were a focus of additional field data collection in the form of survey staff estimates of tree height (±0.5 m), to investigate and compare the population structure of these species, and to determine the invasion status of *T. ramosissima*.

Geospatial analysis

A spectral index classification approach was developed that exploits the deciduous character of *T. ramosissima*, motivated by field observation of the leaves of this species turning orange/brown in winter (Figure 3). This contrast is most stark when viewed against the largely evergreen cover of the indigenous *V. karroo* trees. *Phragmites australis* reed beds also turn brown in winter, but have a much higher leaf area index than *T. ramosissima*, suggesting high spectral separation potential. Accordingly, a differenced normalised difference vegetation index (dNDVI) was developed using Sentinel 2, 10 m resolution image data. This index is commonly used in mapping fire severity (e.g. Franco et al. 2020), where pre- versus post-fire vegetation cover detection differences are similar in principle to summer versus winter cover detection for a deciduous tree species.

Image sets were sourced through the Copernicus Open Access Hub (European Commission, European Space Agency, https://scihub.copernicus.eu/dhus/#/home), for acquisition dates of 2 December 2019 (summer; the acquisition date nearest to the field dGPS vegetation survey date of 8 December 2019), and 15 July 2019 (winter). Sentinel 2 data are geometrically and radiometrically corrected, orthorectified and georeferenced (SUHET 2015). NDVI images were produced for each image set from bands 4 (red) and 8 (near-infrared), following the well-known Equation 1, whereas the dNDVI was derived by Equation 2. Higher positive values of dNDVI indicate lower vegetation vigour in winter relative to summer.

$$NDVI = (NIR − Red)/(NIR + Red) \qquad (1)$$

$$dNDVI = NDVI_{summer} − NDVI_{winter} \qquad (2)$$

dNDVI values were extracted in GIS for the surveyed dGPS cover points, and value distributions for different cover types were compared with identify a threshold value range that could be used to distinguish *T. ramosissima* from other cover types. Five threshold value ranges were used in preliminary dNDVI image classifications (raster reclassification to isolate pixels with dNDVI between 0 and an upper positive threshold value) to test for sensitivity in classification accuracy and identify the best-performing threshold range. dNDVI threshold classifications were evaluated for agreements and disagreements with the field survey dataset following the approach of Pontius
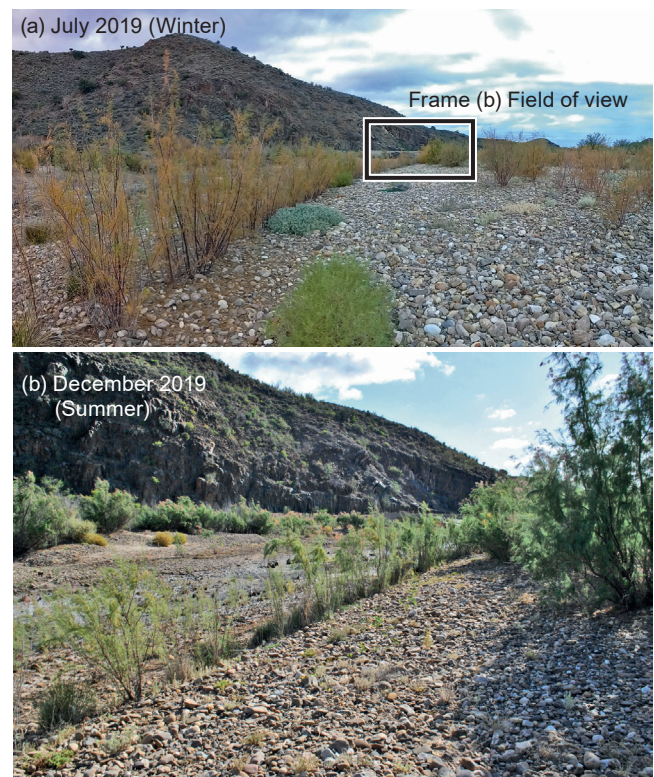

Figure 3: A comparison of photographs of *Tamarix ramosissima* in winter (a; orange/brown foliage) and summer (b; green foliage) of 2019. Note the linear distribution of the plant along a channel margin leading into the large pool shown in Figure 2. The characteristic pink flowers that develop fine wind- and water-dispersed seed are also visible on some plants in Frame B

and Millones (2011). Errors of commission and omission were determined for each classification output, allowing determination of the overall accuracy (agreement), producer's accuracy (100 − omission error), and user's accuracy (100 − commission error) (Coluzzi et al. 2018).

'Agreement' was counted where the location of dGPS survey points for *T. ramosissima* matched the location of pixels classified as this species (the desirable outcome of the classification). 'Omission error' was counted where the location of dGPS survey points for *T. ramosissima* did not match the location of pixels classified as this species (i.e. where the classification failed to detect a stand of the invader). 'Commission error' was counted where the location of dGPS survey points for other plant species matched the location of pixels classified as *T. ramosissima* (i.e. where the classification mistakenly identified another cover type as the invader). Areas of open water were mapped separately using an NDVI threshold on the summer image, and masked from all classifications.

The best-performing dNDVI threshold classification identified through the above error analysis process was used to map and describe the spatial distribution of the invasive tree. Geospatial insights were integrated with field observations to discuss implications for invasion patterns and processes, pool hydrology, and riverscape morphodynamics within the reach.
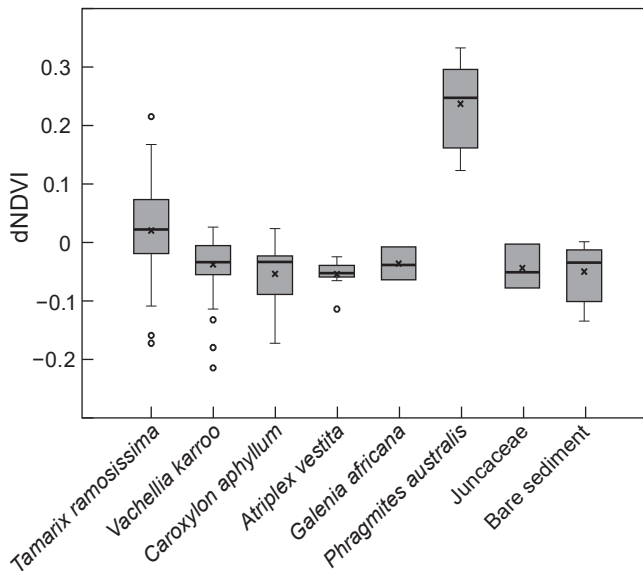
Figure 4: Box-and-whisker plot summary of dNDVI values extracted using the dGPS field survey points, showing the extent of separation of cover types sampled during the survey. Surface water was masked from the classification analyses

Results

dNDVI threshold classification

There was a clear separation in dNDVI values between *T. ramosissima* and other riverscape cover types (Figure 4). Positive values of dNDVI were predominantly associated with *T. ramosissima* and *P. australis*, with the latter species exhibiting much higher positive values than the former, and being confined to a narrow band on the northern margin of the large pool in the survey block. This insight formed the basis of exploring the classification accuracy of a series of dNDVI threshold values (Figure 5). The threshold values used in the sensitivity analysis were selected from the region of the box-and-whisker plot for *T. ramosissima* with minimal to no overlap in dNDVI values with other cover types (Figure 4). Based on the sensitivity analysis, a dNDVI threshold of [0 to 0.2] was considered the best available discriminator of *T. ramosissima* from other cover types in the study area, with an overall accuracy of 59.89%, omission error of 28.25%, and commission error of 11.86% (Figure 5, Table 1).

Lower threshold values produced lower overall accuracy, whereas a higher value encroached on the known dNDVI range of *P. australis* (Figure 4), and was associated with slightly higher commission error and slightly lower overall accuracy (Figure 5). The low commission error of the $dNDVI_{0.2}$ threshold is encouraging, as this indicates a low risk of misclassifying other cover types as *T. ramosissima*. These results indicate that the classification of aerial cover of *T. ramosissima* likely underestimates the true extent of the invasion.

Figure 6 shows the mapped results of the $dNDVI_{0.2}$ threshold classification for the study reach, and illustrates a generally linear, channel/pool margin-associated distribution of *T. ramosissima*. There is an increase in the cover of
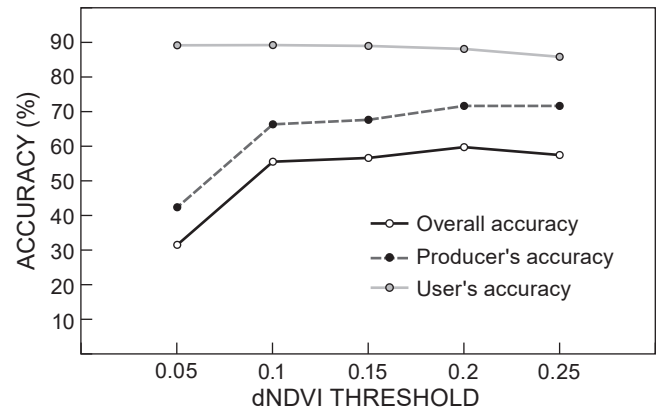
Figure 5: Sensitivity analysis of *Tamarix ramosissima* cover discrimination by dNDVI threshold at the study site

Table 1: Accuracy assessment of the most successful dNDVI threshold classification (dNDVI value range = 0 to 0.2). See Figure 5 for a more detailed evaluation of the dNDVI threshold classifications explored

Agreement %	Omission %	Commission %
59.89	28.25	11.86
Overall accuracy %	Producer's accuracy %	User's accuracy %
59.89	71.75	88.14

T. ramosissima through the middle to lower part of the reach, consistent with the distribution of deeper channels and pools (Grenfell et al. 2021). The invasion covers an area of 80 300 m², which constitutes only 8.21% of the total reach valley floor area mapped, but 65.50% of the total vegetated valley floor area (i.e. at least 65.50% of the vegetation cover of the valley floor of this reach comprises the alien invasive *T. ramosissima*).

Discussion

Comparison with field observations

Observations made during numerous visits to this field site, and other sites across the Touws River catchment since 2017, have highlighted the clearly linear distribution of *T. ramosissima* along the channel, and especially pool, margins (Grenfell et al. 2021; Figure 3). This distribution is consistent with observations in other parts of the world (e.g. Tickner et al. 2001; Cleverly et al. 2002). Some stratification by relative elevation is evident in *T. ramosissima* age structure near the large pool at the field site (Figure 7). Relative elevation in this context is a crude measure of proximity to the pool margin, and of the potential depth to groundwater within the riverscape primary alluvial aquifer (hydrological continuity between pool surface water and the adjacent alluvial aquifer is assumed, given the highly permeable nature of the valley-fill alluvium throughout this reach of the river; Grenfell et al. 2021). The linear distribution of *T. ramosissima* contrasts with the more scattered, and occasionally clustered distribution of *V. karroo* at the site (a distribution observed
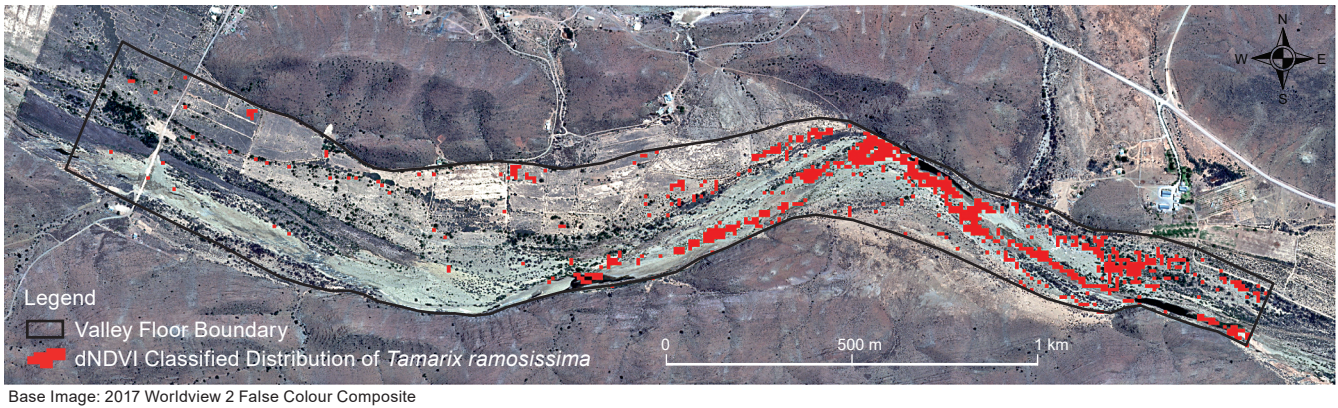
Figure 6: Mapped classification results for the dNDVI$_{0.2}$ threshold classification, showing the linear, channel/pool margin-associated distribution of the invasion
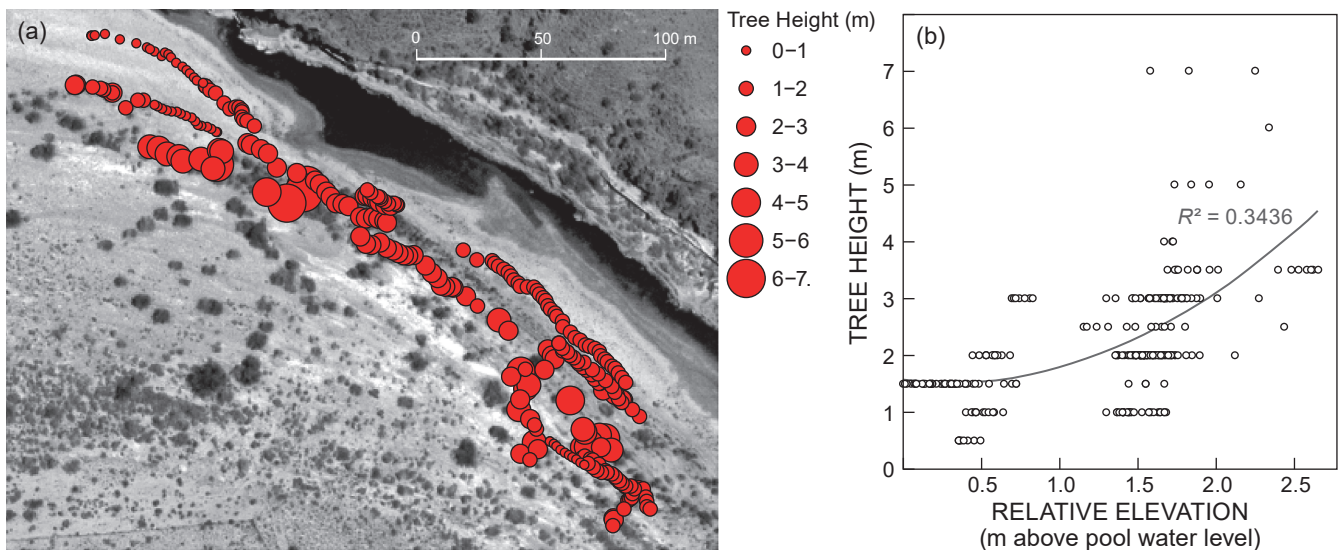
Figure 7: Spatial distribution by height (a) and height/age stratification by relative elevation (b) of *Tamarix ramosissima* near the large pool at the study site. There is a weak second-order polynomial relationship between relative elevation (m above pool water level at the time of survey) and tree height (m), indicating that larger trees are typically encountered farther from the pool on relatively higher elevation surfaces
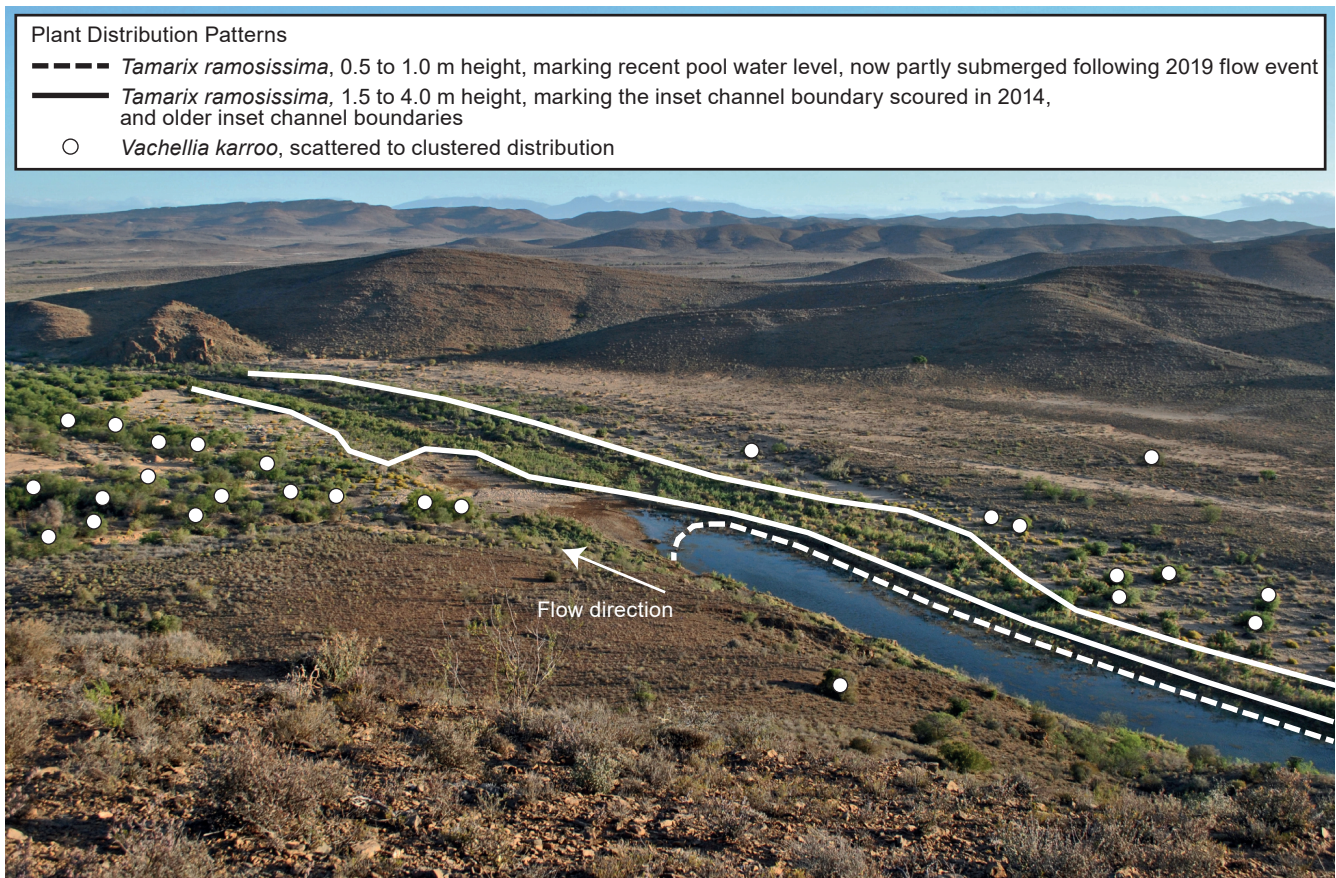
for *Vachellia*'s in other dry riverscape environments; Morgan et al. 2020) (Figure 8).

Observations since 2017 suggest a growth rate for *T. ramosissima* of approximately 0.5 m y^{-1} at the site, although it is likely that this tapers off as the trees reach a maximum height of 4 to 6 m (CABI 2019a). Examination of the population structures of the two dominant tree species (Figure 9) suggests that the invasion of *T. ramosissima* is at a fairly advanced stage, although a large number of individuals in the 0.5 to 1 m height range could not be sampled at the time of the survey, due to inundation following a recent flow event (Figure 8). There is a peak in the population pyramid in the 2 to 3 m height range (~4 to 6 years old, post-2014 flood of ~700 m^3 s^{-1}; Grenfell et al. 2021). There are several individuals greater than 1 m in height (capable of producing flowers), and the large number of individuals in the 1 to 2 m height

range suggests an immediate future trend of increasing robustness of the vegetation structure at channel and pool margins. A few individuals greater than 4 m in height (at least 8 years old) likely represent the progenitor population of *T. ramosissima* at the site, although their exact arrival time is difficult to date without clear insight into the date of introduction of this species to the region (introduction to South Africa is referred to as recent, post-2000, by CABI 2019a). The population pyramid of *V. karroo* also has a peak in the 2 to 3 m height range (Figure 9), but has a more extended tail in the distribution toward taller (older) individuals than *T. ramosissima*, suggesting an ageing population.

Patterns and processes of the invasion

The dNDVI threshold approach is a relatively simple classification that exploits a known, predictable and

Plant Distribution Patterns

– – –   *Tamarix ramosissima*, 0.5 to 1.0 m height, marking recent pool water level, now partly submerged following 2019 flow event
———   *Tamarix ramosissima*, 1.5 to 4.0 m height, marking the inset channel boundary scoured in 2014, and older inset channel boundaries
○   *Vachellia karroo*, scattered to clustered distribution

Flow direction

Figure 8: Oblique aerial photograph taken facing south-southeast across and downstream, from a hilltop adjacent to the large pool (pictured) within the study site. Annotations provide a field-informed interpretation of vegetation distribution and height/age structure (Photograph: Suzanne Grenfell)
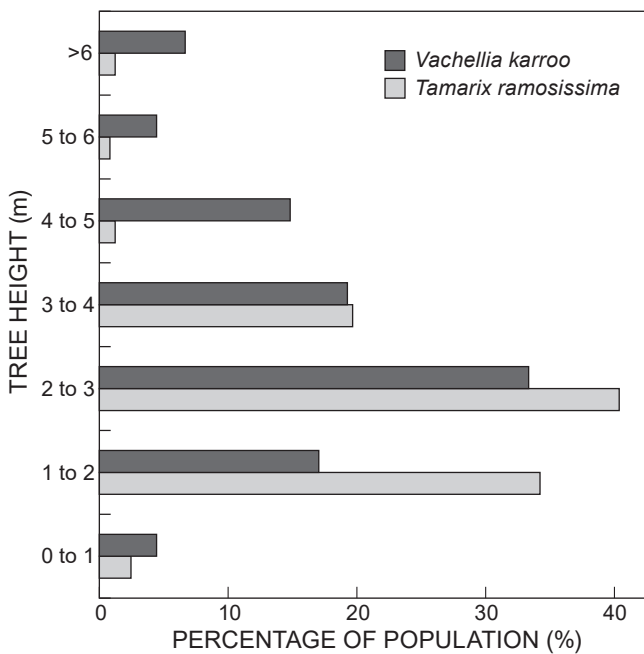
Figure 9: Population pyramids based on tree height (~age) for *Tamarix ramosissima* and *Vachellia karroo* at the study site

observable seasonal vegetation response in the target species, which evidently produces a strong and clear index signature, when this is explicitly isolated. This strong biophysical basis, and the low commission error of the classification, as well as the cost-free availability of Sentinel 2 data, encourage the application of dNDVI as a classification approach for additional mapping of *T. ramosissima* in riverscapes of the Klein Karoo. The results underestimate the true extent of the invasion, but a conservative (low commission error) underestimate is better than an erroneous overestimate.

Differences in tree distribution and age structure between *T. ramosissima* and *V. karroo* (Figures 8 and 9) suggest a germination/colonisation advantage for the invasive, especially in pool-margin locations. Given the hydrology and physico-chemistry of the region (Le Maitre et al. 2007, 2009), this advantage likely result from differences in tolerance limits for water stress and/or salinity (Tickner et al. 2001). The Adolphspoort Formation shale base lithology of this reach of the Touws River, yielding only a slow bleed of saline groundwater discharge to the pool, coupled with the episodic nature of rainfall events and ephemerality of freshening connecting flows, leads to a condition of evaporation-driven surface water salinity within the large pools that characterise the hydro-geomorphic pattern of the dominant no-flow state of the system (Grenfell et al. 2021). It is therefore possible that

T. ramosissima is tolerant of higher salinities than *V. karroo*, although both species are considered salt tolerant (see CABI 2019a for *T. ramosissima*, and CABI 2019b for *V. karroo*).

Although *T. ramosissima* seed can germinate rapidly at channel or pool margins following a flood, and continue to grow as surface and phreatic water levels decline, the germination of seed and sustained growth of seedlings of *V. karroo* likely requires a favourable rainfall (Steenkamp et al. 2008) or flooding (Jacobson et al. 1995) regime during the first few years of growth; sufficient to allow roots to penetrate into the subsurface dry period water supply, and to allow the development of above ground structures capable of withstanding subsequent flood damage (Jacobson et al. 1995). Poor recruitment of *Vachellia*'s in some riverscape environments has also been linked to high concentrations of browsers (Steenkamp et al. 2008). Browsing by greater kudu (*Tragelaphus strepsiceros*) has been observed in the study area.

The relatively weak, but observable, stratification of *T. ramosissima* height by relative elevation/proximity to the pool margin/depth to groundwater (Figure 7) is indicative of historical variation in pool margin location at the site (stratification driven by pool morphological change in response to flood events; Grenfell et al. 2021), but also of tolerance for a broad range of hydro-edaphic conditions (Tickner et al. 2001). Some stands of *T. ramosissima* at the site survived prolonged shallow inundation of the root zone for more than six months in 2018, and continued to produce flowers from emergent stems, whereas other stands relatively far from the present pool location have survived lengthy dry periods (e.g. total rainfall for Plathuis in 2017 was 56 mm). The above observations highlight the important role of spatio-temporal 'windows of opportunity' in determining dispersal, germination and establishment patterns of vegetation in riverscape environments (Jacobson et al. 1995; Kleinhans et al. 2018, 2019).

Implications for riverscape dynamics and further research
Non-perennial rivers display a diversity of vegetation patterns and densities (e.g. Tooth and Nanson 2004; Dunkerley 2014; Morgan et al. 2020), and the tree species considered here have contrasting linear stand-forming (*T. ramosissima*) and obstacle-forming (*V. karroo*) growth patterns (Grenfell et al. 2021), such that the invasion is likely to lead to a change in morphodynamics mediated by hydraulic interactions between both living plants and their woody-debris products (Wohl et al. 2019). Although *V. karroo* stems and debris piles are associated with forced midchannel bars (Grootboom 2019; Grenfell et al. 2021) that create riverscape topographic diversity, the linear channel-flanking growth pattern of *T. ramosissima* could lead to macrochannel entrenchment and reduced channel-floodplain connectivity (Grenfell et al. 2021). Understanding these differences in growth characteristics is key to developing dynamic hydraulic roughness formulations for application in morphodynamic models (e.g. Bertoldi et al. 2014; Van Oorschot et al. 2016; Grenfell et al. 2021), which may be applied to evaluate the biomorphodynamic efficacy of the invasion (Bertoldi et al. 2014), and its effects on riverscape structure and function in more detail (Rowntree 1991; Dollar et al. 2007).

Understanding the full implications of the invasion by *T. ramosissima* for pool water balances will require further work on local water use by this species. However, a comprehensive review by Stromberg et al. (2009) showed that stand-level estimates of actual evapotranspiration by *Tamarix* spp. across the western United States ranged narrowly from 750 to 1 450 mm y^{-1}, with a mean value of approximately 1 000 mm y^{-1}. Observations of actual evapotranspiration from *T. ramosissima* stands using three-dimensional eddy covariance were reported by Cleverly et al. (2002) for a similar climatic and riverscape setting in New Mexico, USA. Evapotranspiration from an unflooded site was 740 mm y^{-1}, and from a regularly flooded site was 1 220 mm y^{-1}. The local mean annual potential A-Pan evaporation of the Plathuis study site is 2 253.2 mm (Schulze and Maharaj 2007). A potential additional draw of ~1 000 mm y^{-1} by *T. ramosissima* in the vicinity of the Touws River pools is a particular concern for the ecology of the river, as pools in non-perennial rivers serve as key aquatic refugia during extended no-flow periods (Hamilton et al. 2005; Seaman et al. 2010; Sheldon et al. 2010; Biggs et al. 2017; Jaeger et al. 2017). The enhanced drawdown may also be associated with more rapid salinisation of pool surface waters than would naturally occur, although this has not been explicitly evaluated in the current study.

In light of the above, the spatio-temporal distribution and recruitment characteristics of *T. ramosissima* and *V. karroo* could provide a useful biomonitoring and EcoStatus determination tool for the evaluation of river ecological condition and environmental water requirements in this catchment (e.g. Kleynhans et al. 2008), with the potential to indicate spatial variation (and changes) in the magnitude and chemistry of groundwater discharge, the likelihood of enhanced drawdown and salinisation of aquatic refugia, and the threat of longer-term modification to eco-morphodynamics and physical habitat structure and function. The current monitoring approach for the Touws River (DWS 2015) uses macroinvertebrate indicators that are poorly suited to non-perennial river environments (Watson and Dallas 2013), and is applied only during periods of flow, which are typically short-lived (Grenfell et al. 2021).

Conclusion

A field-informed dNDVI classification approach was developed to map the spatial distribution of an invasion by *Tamarix ramosissima* Ledeb. within a reach of the Touws River in the Klein Karoo, South Africa. The overall accuracy of the classification was ~60%, with a bias toward under- rather than overestimation of IAP cover. The invasion currently accounts for at least 65% of the total vegetated valley floor area, and is focused in a linear distribution along channel margins. The linear distribution of the IAP contrasts sharply with the scattered distribution of the previously dominant indigenous sweet thorn, *Vachellia karroo*, such that a change in eco-morphodynamic processes and physical habitat structure and function is likely in the coming decades. It is argued that such insights could be valuably applied in EcoStatus determination in non-perennial river

systems, where conventional perennial river bio-indicators often fail to provide appropriate insight into the condition and trajectory of the ecosystem.

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