

RESEARCH ARTICLE

Open Access

Aerial spot treatment using an oil carrier to apply ester based herbicides for control of *Pinus contorta* and *P. nigra* in New Zealand

Stefan Gous¹, Peter Raal² and Michael S Watt^{3*}

Abstract

Background: Invasive wilding conifer species are a major threat to biological conservation in New Zealand. Scattered individual plants are particularly problematic as these are very costly to treat and once they reach reproductive maturity can act as point sources for further invasion. A novel method is described in this paper that delivers a precise dose of oil-based herbicide mixtures into the tree crown via a hand held lance using a helicopter as a platform. Using this method the objective of this research was to test the efficacy of six triclopyr based herbicides in an oil carrier, on isolated naturally occurring *Pinus contorta* (Dougl.) and *P. nigra* subsp. *laricio* (Poir.) Maire.

Methods: For each species and treatment combination treated trees covered a wide range of heights, ranging from ca. 0.5 to 16 m. Measurements of mortality taken 24 months post herbicide application were used to examine variation in efficacy of these herbicides, where successful treatment was defined by a mortality rate of 85% or higher. Logistic regression models were fitted for each species and from these models we determined the threshold tree height at which 85% mortality occurred, H_{85} .

Results: For both species treatment efficacy significantly ($P \leq 0.05$) declined as tree height increased. The two most effective treatments for both species were a 500 mL dose that included 60 g triclopyr in oil with addition of 1% alkylsilicone surfactant (20 G OM 500 mL) and a 1 litre dose that included 120 g triclopyr and 20 g picloram in oil (10G T20). Values of H_{85} for 10G 20T and 20 G OM 500 mL were, respectively, 7.7 m and 8.0 m for *P. contorta* and 7.1 m and 6.8 m for *P. nigra*.

Conclusion: Spot application of triclopyr based herbicides, in an oil carrier, onto the tree crown was found to be an effective means of controlling two of the most vigorous New Zealand wilding conifer species.

Keywords: Wilding conifers; Aerial spot spraying; Herbicides

Background

Exotic conifer species were planted mainly for erosion control during the late 1880s (Ledgard 2001) throughout New Zealand. Most of these conifers are primary colonisers and have naturally regenerated from these plantings. Since then, these conifers, known as wildings, have spread extensively, and the total area in which wilding conifers occur in the South Island of New Zealand is estimated to be in excess of 500,000 ha (Raal and Gous 2010). The spread of these conifer species into a wide variety of habitats in New Zealand would result in a significant loss of

natural landscape value and biodiversity if the trees were to become fully established throughout their potential distribution ranges (Raal and Gous 2010). *Pinus contorta* (Dougl.), the most invasive wilding conifer within New Zealand, constitutes two thirds of wilding pines on land administered by the Department of Conservation (DOC) (Ledgard 2001).

Scattered individual wilding conifers, are particularly problematic as the greater flying time required to reach them makes them more expensive to control than dense infestations. If not killed, these isolated wilding conifers can provide a point source for further invasion when they reach reproductive maturity. Consequently, control of isolated outlier trees is an essential element of any

* Correspondence: michael.watt@scionresearch.com

³Scion, PO Box 29237, Christchurch, New Zealand

Full list of author information is available at the end of the article

management plan that aims to slow the dispersal of wilding conifers (Ledgard 2001). Despite this, there are few cost-effective chemical methods described in the literature for controlling sparsely distributed wilding conifers (Ray and Davenport 1991). Current operational methods to control sparse and scattered wildings rely mainly on felling by chainsaw (Ledgard 2009). Due to the isolation and remoteness of these wilding conifers, a chainsaw operator has to be flown to each tree to cut it down. This method, operationally known as skid-hopping, is costly, dangerous and time consuming (P. Willemse, DOC, Twizel, 2011, pers. comm.).

A novel method is described in this paper that delivers a precise dose of oil-based herbicide mixtures to the tree crown via a hand-held lance using a helicopter as a platform. The carrier oil greatly enhances spread, penetration and uptake of the herbicide through the bark into the plant. This enhanced uptake allows the herbicide to be applied during periods when the wildings are not actively growing, which extends the time period over which conifers can be treated.

Using this method, the efficacy of six triclopyr-based herbicides in oil were tested on naturally occurring *P. contorta* and *P. nigra* subsp. *laricio* (Poir.) Maire wildings. The efficacy of the treatments, 24 months following application, is described.

Methods

Trial locations

Due to the dispersed distribution of *P. contorta* and *P. nigra* wildings, the trial area within which the treatments were applied needed to be large (landscape level). The trial on *P. contorta* was conducted on Mackenzie District Council land, 5 km north of Twizel (latitude: 44° 12' 36" longitude 170° 08' 10", elevation 500 m a.s.l.). Mean annual air temperature for this site is 8.9°C and mean total annual rainfall is 627 mm year⁻¹ (CliFlo: <http://cliflo.niwa.co.nz>, retrieved 4-April-2014). Seasonal water deficits regularly occur at this site as a result of the lower

precipitation, high evapotranspiration level and low soil moisture storage.

The trial on *P. nigra* was conducted on Braemar Station land near Mt Cook (latitude: 43° 50' 52" longitude 170° 11' 36", elevation 700 m a.s.l.). Mean annual air temperature for this site is 8.4°C and mean total annual rainfall is 1,790 mm year⁻¹ (CliFlo: <http://cliflo.niwa.co.nz>, retrieved 4-April-2014).

Both sites are characteristic of well-drained areas that support fescue tussock in a thick layer of free draining Pleistocene fluvio-glacial outwash gravels overlying Tertiary sediments. Prevailing winds are from the north-west.

Treatments and application

In total, six herbicide treatments and a control (paraffinic oil alone) were tested (Table 1). The six herbicide treatments were based on the systemic pyridine herbicide, triclopyr butoxyethyl ester and included two rates of triclopyr (60 g or 120 g triclopyr). Picloram (20 g) was added to one treatment (Table 1). The trade names of the herbicides used were Grazon and Tordon (Dow AgroSciences, Indianapolis, USA).

The treatments included 10G, 10G 20T and 20G which comprised, respectively, 60 g triclopyr, 120 g triclopyr plus 20 g picloram and 120 g triclopyr, applied in a total volume of 1,000 mL to the tree. The treatment 20G GO was identical to 20G apart from the use of the carrier oil Genera (Total Oil Asia-Pacific, Singapore) rather than paraffinic oil. The treatment 20G OM 1 litre included 120 g triclopyr in a total spray volume of 1,000 mL while the treatment 20G OM 500 mL comprised 60 g triclopyr in a spray volume of 500 mL. The alkylsilicone surfactant Oil Mate was added to both of these treatments and constituted 1% of the total spray volume (Table 1). The treatment with the 500 mL dosage was included to examine the sensitivity of both wilding species to spray application volume.

Experimental units consisted of individual trees. The number of trees per herbicide treatment ranged from 40 – 50 for *P. contorta* and 25 – 41 for *P. nigra*. The height

Table 1 Herbicides, carriers, active ingredients and application volumes used for both trials to control *P. contorta* and *P. nigra* by means of aerial spot application into the tree crowns

Treatment	Herbicide	Carrier	Active ingredient tree ⁻¹	Volume tree ⁻¹ (mL)
Para. oil		100% Paraffinic (Para.) oil		1000
10 G	10% Grazon	90% Para. oil	60 g Triclopyr	1000
10 G 20 T	10% Grazon + 20% Tordon	70% Para. oil	120 g Triclopyr 20 g Picloram	1000
20 G	20% Grazon	80% Para. oil	120 g Triclopyr	1000
20 G GO	20% Grazon	80% Genera oil	120 g Triclopyr	1000
20 G OM 1 litre	20% Grazon	79% Para. oil + 1% Oil mate	120 g Triclopyr	1000
20 G OM 500 mL	20% Grazon	79% Para. oil + 1% Oil mate	60 g Triclopyr	500

range of these trees are summarised by species and treatment in Table 2.

Herbicide treatments were applied using a custom-built, hand-operated spot gun, developed by Scion and DOC. The platform from which the herbicides were applied was a MD 520 N NOTAR helicopter. The spot-gun applicator was calibrated to deliver the required application volume per tree (Table 1). Herbicides were applied to the tree crown from an average distance of 4 m. Treatments were applied in December 2010.

Damage assessments

Tree mortality was recorded 24 months following the treatment as the percentage of live foliage in increments of 10%. Each tree was visually assessed from the ground by dividing it into three sections from top to bottom and sections were scored individually, then averaged to obtain a whole-tree score. A tree with no damage was given a score of 100% and a dead tree received a score of 0% (no live foliage). A treatment was considered to be effective when a mortality rate of over 85% was reached.

Analysis

All analyses were undertaken using SAS software (SAS-Institute-Inc. 2008). As the treated trees were randomly dispersed within each trial area, analyses were undertaken at the tree level. The main and interactive effects of treatment and tree height on mortality were examined for each species using a logistic model. In this model, treatment was included as a class level variable while

Table 2 Summary of the number and height of trees selected for each treatment by species

Treatment	Tree number and height			
	Freq. (no.)	Min. (m)	Mean (m)	Max (m)
<i>Pinus contorta</i>				
Paraffinic oil	50	1.5	5.6	15
10 G	50	2.0	6.7	16
10 G 20 T	50	0.5	7.9	15
20 G	50	1.5	4.5	11
20 G GO	50	3.0	6.5	11
20 G OM 1 litre	47	4.0	5.8	14
20 G OM 500 mL	40	3.0	8.0	16
<i>Pinus nigra</i>				
Paraffinic oil	40	2.0	4.5	13
10 G	25	2.0	5.0	15
10 G 20 T	41	1.5	5.2	10
20 G	25	1.0	4.3	12
20 G GO	25	5.0	9.5	14
20 G OM 1 litre	25	4.0	8.9	15
20 G OM 500 mL	25	6.0	10.4	14

wilding height was included as a continuous covariate for which the significance of linear and polynomial terms were tested. A test of model fit was undertaken using the Hosmer-Lemeshow test with high *P* values signifying good correspondence between predicted and measured mortality.

Using parameter values extracted from the final two models, dose-response functions for each treatment were generated by plotting predicted mortality against tree height. The two models were used to derive threshold heights for each treatment × species combination below which mortality was predicted to be greater than the threshold value of 85% (H_{85}) using the following procedure.

If the logistic regression model relating mean percentage of dead trees *Y* to tree height *H* is:

$$Y = 100 \times \exp(a + b \times H) / (1 + \exp(a + b \times H)) \quad (1)$$

then, the height H_{85} when mortality is predicted to be 85% is:

$$H_{85} = (L - a) / b \quad (2)$$

where *L* is the logit of 85%, i.e.,

$$L = \ln(85/100) - \ln(1 - 85/100) = 1.74 \quad (3)$$

Results

For both species, the main effects of height and treatment had a highly significant influence ($P < 0.001$) on mortality, but the interaction was not significant ($P > 0.05$) (Table 3). Both models of mortality fitted the data well with values for the Hosmer Lemeshow statistic significantly exceeding $P = 0.05$ for both *P. contorta* ($P = 0.19$) and *P. nigra* ($P = 0.92$). Parameter values for both models are shown in Table 4.

There was a highly significant and marked decline in treatment efficacy with increasing tree size for both *P. contorta* and *P. nigra* (Figure 1). Dose response curves for both species (Figure 1) show that the control (which contained only paraffinic oil) caused little *P. contorta* mortality and moderate *P. nigra* mortality. Mortality for this treatment did not reach the threshold of 85% for

Table 3 Influence of the main and interactive effects of treatment and height on mortality

Term	<i>P. contorta</i>	<i>P. nigra</i>
Treatment (T)	64.2***	36.1***
Tree height (H)	77.8***	30.4***
T × H	3.7 ^{ns}	2.7 ^{ns}

Shown for both species are the *F*-values followed by the *P* category with the asterisks ***denoting significance at $P = 0.0001$ and ^{ns}indicating no significance at $P = 0.05$.

Table 4 Model parameters and predictions from the logistic model of mortality

Treatment	Model statistics	
	Trt offset	H_{85}
<i>Pinus contorta</i>		
Paraffinic oil	-6.3232	-
10 G	0.463	6.5
10 G 20 T	1.4097	7.7
20 G	0.3855	6.4
20 G GO	1.4652	7.7
20 G OM 1 litre	0.9161	7.0
20 G OM 500 mL	1.6837	8.0
<i>Pinus nigra</i>		
Paraffinic oil	-4.1388	-
10 G	0.827	6.5
10 G 20 T	1.4768	7.1
20 G	0.1157	5.8
20 G-GO	0.2406	5.9
20 G OM 1 litre	0.2606	5.9
20 G OM 500 mL	1.2181	6.8

Shown are the treatment offset in the logistic model and model predictions of the maximum height at which 85% mortality is achieved (H_{85}). No estimate is given for the paraffinic oil treatment as a mortality of 85% was not reached for this treatment. Estimated values for the slope and intercept in the logistic model were, respectively, 6.404 and -0.7922 for *P. contorta* and, respectively, 7.4723 and -1.0167 for *P. nigra*.

either species (Figure 1). For the six herbicide-containing treatments, there was a marked reduction in herbicide efficacy for those trees with heights in excess of 7 m (Figure 1).

For both species, the predicted mortality across the height range was highest using the 10G 20T and 20 G OM 500 mL treatments (Figure 1), and values of H_{85} for these two treatments were 7.7 m and 8.0 m respectively for *P. contorta* and 7.1 m and 6.8 m for *P. nigra* (Table 4). The 20 G GO treatment also had a high impact on *P. contorta* (Figure 1) and the value of H_{85} was 7.7 m for this treatment (Table 4). For both species, the 20G treatment was associated with the lowest mortality over the height range (Figure 1) and values of H_{85} for this treatment were 6.4 m and 5.8 m for *P. contorta* and *P. nigra* respectively.

A comparison of the baseline treatment (20G) with those treatments containing the same quantity of active ingredient (120 g triclopyr), but with differences in additives and oils, showed some variation. For *P. contorta* values of H_{85} were higher when Genera oil rather than paraffinic oil (Table 4) was used as a carrier of 120 mL of triclopyr tree⁻¹ (7.7 vs. 6.4 m) but little variation in H_{85} was noted between these two treatments for *P. nigra* (5.9 vs. 5.8 m). The addition of an alkylsilicone surfactant to 120 g of triclopyr increased values of H_{85} for

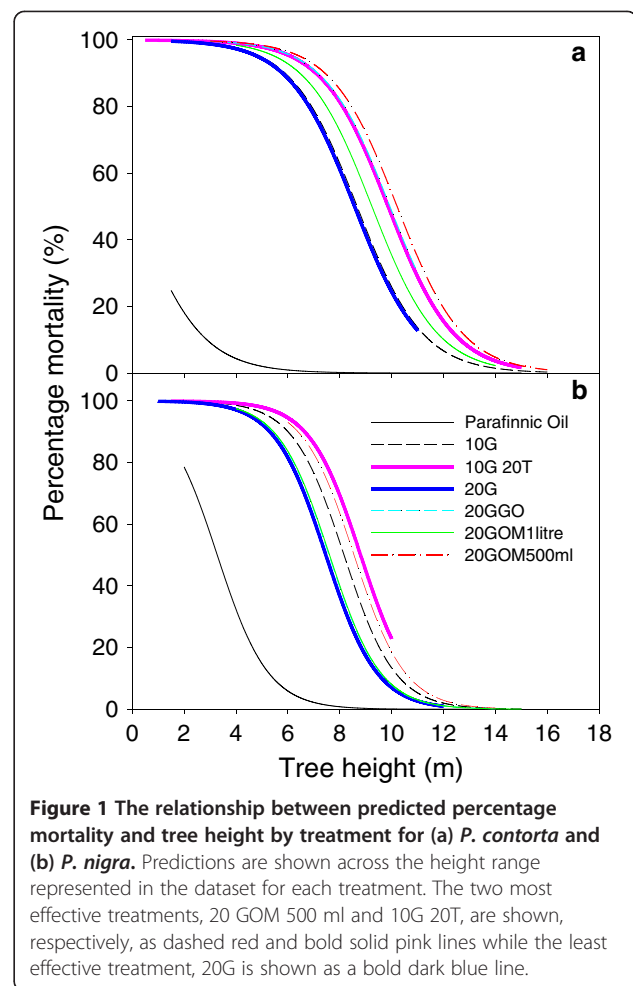


Figure 1 The relationship between predicted percentage mortality and tree height by treatment for (a) *P. contorta* and (b) *P. nigra*. Predictions are shown across the height range represented in the dataset for each treatment. The two most effective treatments, 20 GOM 500 ml and 10G 20T, are shown, respectively, as dashed red and bold solid pink lines while the least effective treatment, 20G is shown as a bold dark blue line.

both species, but this addition was far more marked for *P. contorta* (7.0 vs. 6.4 m) than *P. nigra* (5.9 vs. 5.8 m). Surprisingly, the treatment with 60 g triclopyr was more effective than the treatment with 120 g triclopyr for both *P. contorta* (8.0 vs. 7.0 m) and *P. nigra* (6.8 vs. 5.9 m) even though treatments included the same carrier (paraffinic oil) and rate of alkylsilicone surfactant.

Discussion and conclusion

This method of application represents a considerable advance in the control of isolated wilding conifer species. Aerial application of the two most effective treatments from a calibrated spot gun allowed successful control of both *P. contorta* and *P. nigra* up to a height of ca. 7 – 8 m. As flying time between trees is much reduced this method is considerably faster than the previous operational practice of skid hopping. Given the effectiveness of the treatment and the speed of the operation this method has been successfully adopted by DOC for the operational control of isolated wilding pines (*P. Willemse*, DOC, Twizel, 2012, pers. comm.).

Overall, the two most effective treatments were the 1,000 mL dose of 120 g triclopyr and 20 g picloram in paraffinic oil (10G 20T) and the 500 mL dose that contained 60 g triclopyr in paraffinic oil with an alkylsilicone surfactant added (20 G OM 500 mL). It was interesting to note that application of 50% of the triclopyr dose (20 G OM 500 mL) in combination with an alkylsilicone surfactant resulted in similar mortality for both species as the full triclopyr dose (120 g triclopyr) that also included picloram but did not have the alkylsilicone surfactant (10G 20T).

Alkylsilicones are oil-soluble surfactants that enhance the coverage of plant and petroleum-derived spray oils on target plants (Gaskin et al. 2002) and the high efficacy of the 20 G OM 500 ml treatment could be attributed to the enhanced coverage. Surprisingly, application of twice the dose of the 20 G OM 500 mL treatment with the alkylsilicone surfactant (i.e. 1,000 vs. 500 mL) was markedly less effective for both species than the lower dose. However, this high volume treatment (20 G OM 1 litre) was more effective than the similar treatment without the alkylsilicone surfactant (20 G) for both species. One limitation of this research was that treatment dosages, oil volumes and surfactants were not combined in a factorial arrangement. The low number of combinations of these factors limits the extent to which results can be interpreted. Further research should focus on the most effective treatments found in this study and examine more fully the effect of herbicide dosage, tree size, alkylsilicone surfactant and oil volume on mortality. Dose response functions should be constructed for each treatment that are sensitive to these four factors.

Aerial delivery of a calibrated herbicide dose using a spot gun is a far more efficient practice than the previously used operational practice of skid-hopping. Through use of this method operationally DOC has noted marked reductions in the time required to treat each tree. Anecdotal information indicates treatment duration per tree to be at least five minutes for skid hopping and *ca.* 15 seconds using the method described in this paper (P. Willemse, DOC, Twizel, 2011, pers. comm.). Aerial application also eliminates the dangers associated with manual control (P. Willemse, DOC, Twizel, 2011, pers. comm.). These advantages are consistent with previous research that has found chemical treatments to be more cost effective and safer to use than those of ground-based vegetation management such as brush cutting and use of chainsaws (Fortier and Messier 2006; Dampier et al. 2006).

This method of application has the potential to promote the re-establishment of grasses and native tussocks within the treated areas. Herbicide damage to surrounding tussock and grassland is unlikely as the application is directed at, and confined to, the tree crown. In addition, triclopyr and picloram have little effect on monocotyledon

plants. Inclusion of picloram within the mixture may be beneficial as this active ingredient has extended soil persistence and activity (up to 450 days after treatment, MacDiarmid 1975), when compared with triclopyr. Extended persistence in the soil and the consequent ongoing prevention of conifer germination may provide an opportunity for tussocks and grass species to regenerate and provide a cover that prevents future conifer establishment.

The use of oil rather than water as a carrier of soluble esters, such as triclopyr, extends the period over which trees can be treated. Penetration of the herbicide into the tree is through the bark which allows the solution to be applied, to trees with dry bark at any time of the year (Jackson and Finley 2013). Herbicide applications during the dormant winter period onto trunks with dry bark will penetrate the bark and kill the tree once translocation occurs during the spring flush (Rathfon and Ruble 2006).

This study demonstrates effective control of *P. con tortora* and *P. nigra* up to *ca.* 7 – 8 m, through the spot application of triclopyr-based herbicides in an oil carrier, to the tree crown. This method is far more rapid and safe than the current practice of skid-hopping. Further research should develop dose response functions for the most effective treatments that are sensitive to herbicide dosage, tree size, alkylsilicone surfactant and oil volume. A focus of further research should also be to develop a herbicide prescription that can consistently kill larger trees over *ca.* 8 m.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

SG was the primary author and co-designed the study. PR undertook all field measurements and co-designed the trial. MSW was the secondary author and undertook all analyses. All authors have read and approved the final manuscript.

Acknowledgements

This project was funded by the FRST contract Beating weeds 2 (Contract No. COOX0504). Thanks to Peter Willemse, Department of Conservation, Twizel, for taking care of all logistics, i.e. site selection, herbicide delivery and helicopter availability. We also thank Mark Kimberley for advice on the statistical analysis.

Author details

¹Scion, Private Bag 3020, Rotorua, New Zealand. ²Department of Conservation, Otago Conservancy, PO Box 5244, Dunedin, New Zealand. ³Scion, PO Box 29237, Christchurch, New Zealand.

Received: 4 April 2014 Accepted: 11 September 2014

Published online: 09 October 2014

References

- Dampier, JEE, Bell, FW, St-Amour, M, Pitt, DG, & Luckaj, NJ. (2006). Cutting versus herbicides: tenth-year volume and release cost-effectiveness of sub-boreal conifer plantations. *Forestry Chronicle*, *82*, 521–528.
- Fortier, J, & Messier, C. (2006). Are chemical or mechanical treatments more sustainable for forest vegetation management in the context of the TRIAD? *Forestry Chronicle*, *82*, 806–818.
- Gaskin, RE, Bradley, SJ, Manktelow, DWL, & Zabkiewicz, JA. (2002). Enhancement of plant- and petroleum-derived spray oils with alkylsilicone surfactants. In

- GAC Beattie (Ed.), *Spray Oils Beyond 2000: Sustainable Pest and Disease Management* (pp. 56–61). Sydney: University of Western Sydney.
- Jackson, DR, & Finley, JC. (2013). Using basal bark herbicide applications to control understory tree species. <http://pubs.cas.psu.edu/FreePubs/PDFs/ee0059.pdf>. Accessed 7 February 2014.
- Ledgard, N. (2001). The spread of lodgepole pine (*Pinus contorta*, Dougl.) in New Zealand. *Forest Ecology and Management*, *141*, 43–57.
- Ledgard, NJ. (2009). Wilding control guidelines for farmers and land managers. *New Zealand Plant Protection*, *62*, 380–386.
- MacDiarmid, BN. (1975). Soil residues of picloram applied aerially to New Zealand brushweeds. *Proceedings of the New Zealand Weed and Pest Control Conference*, *28*, 109–114.
- Raal, P, & Gous, SF. (2010). *Literature review of herbicides to control wilding conifers. (Scion report no. 17750)*. Rotorua, New Zealand: Scion.
- Rathfon, R, & Ruble, K. (2006). Herbicide treatments for controlling invasive bush honeysuckle in a mature hardwood forest in west-central Indiana. In *Proceedings 15th Central Hardwood Forest Conference* (pp. 187–197). Knoxville: U.S. Department of Agriculture Forest Service, Southern Research Station.
- Ray, JW, & Davenport, NA. (1991). Evaluation of herbicides for the control of *Pinus contorta*. In *Proceedings of the Forty-Fourth New Zealand Weed and Pest Control Conference* (pp. 21–24). Rotorua: New Zealand Plant Protection Society.
- SAS-Institute-Inc. (2008). *SAS/STAT 9.2 User's Guide*. Cary: SAS Institute Inc.

doi:10.1186/s40490-014-0023-6

Cite this article as: Gous et al.: Aerial spot treatment using an oil carrier to apply ester based herbicides for control of *Pinus contorta* and *P. nigra* in New Zealand. *New Zealand Journal of Forestry Science* 2014 **44**:23.

Submit your manuscript to a SpringerOpen[®] journal and benefit from:

- Convenient online submission
- Rigorous peer review
- Immediate publication on acceptance
- Open access: articles freely available online
- High visibility within the field
- Retaining the copyright to your article

Submit your next manuscript at ► springeropen.com
