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An ecosystem services approach to the ecological effects of salvage logging: valuation of seed dispersal

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Abstract. Forest disturbances diminish ecosystem services and boost disservices. Because post-disturbance management intends to recover the greatest possible value, selling timber often prevails over other considerations. Ecological research has shown diverse effects of salvage logging, yet such research has focused on the biophysical component of post-disturbance ecosystems and lacks the link with human well-being. Here we bridge that gap under the ecosystem services framework by assessing the impact of post-fire management on a non-timber value. By employing the replacement cost method, we calculated the value of the post-fire natural regeneration of Holm oaks in southern Spain under three post-fire management options by considering the cost of planting instead. The value of this ecosystem service in non-intervention areas doubled that of salvage-logged stands due to the preference for standing dead trees by the main seed disperser. Still, most of the value resulted from the resprouting capacity of oaks. The value of this and other ecosystem services should be added to traditional cost/benefit analyses of post-disturbance management. We thus call for a more holistic approach to salvage logging research, one that explicitly links ecological processes with human well-being through ecosystem services, to better inform decision-makers on the outcomes of post-disturbance management.

Key words: economic valuation; ecosystem service; Garrulus glandarius; Quercus ilex; *salvage harvesting; wildfire.*

INTRODUCTION

Management decisions after large disturbances are critical for the pace and direction of ecosystem regeneration. Disturbances generate fear and anxiety in affected human populations due to the destruction of property and sentimental places, leading to the instinctive craving for *someone to do something* to erase the signs of the *calamity* (Lindenmayer et al. 2017). Large recent disturbances (such as the 2016 Fort McMurray Fire, which affected more than half a million hectares), along with observed and projected increases in average disturbance size, frequency, and severity due to global change (Kurz et al. 2008, Johnstone 2016), generate the need to define post-disturbance management strategies that enhance natural regeneration, favor the quick recovery of natural populations and ecosystem services, and limit potential disservices generated by the disturbance (CBD 2001, Thom and Seidl 2015). Although disturbances are recognized as natural processes in many ecosystems of the world, along with positive effects on ecosystem functioning and biodiversity under historical disturbance cycles (Noss et al. 2006, Christensen 2014, Lindenmayer et al. 2017), they are usually unplanned, and often undesired, events that require subsequent decision-making.

A common strategy of managing forests affected by wildfires, storms, and insect outbreaks is felling and extracting the affected wood. This is usually performed in order to recover some part of the value of the affected timber (i.e., to reduce the loss of a provisioning ecosystem service), thus leading to the term *salvage* logging (Lindenmayer et al. 2008). In addition, it is often claimed that widespread salvage logging reduces the risk of subsequent fire or pest outbreaks, favors the natural regeneration of the plant community, or eases the transit through the affected area (Stokstad 2006, Lindenmayer et al. 2008). 2 Salvage logging is thus conducted as a means of securing the greatest (remaining) value from the disturbed forest.

A report in 2000 (McIver and Starr 2000), however, highlighted the lack of empirical evidence regarding the ecological implications of salvage logging. Since,

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numerous studies have revealed that this practice may not only lack the desired effects but may actually have opposite effects, such as an increase in fire risk, the hampering of natural regeneration, and the loss of habitat for species of conservation interest (Donato et al. 2006, Lindenmayer et al. 2008, Leverkus et al. 2014, Thorn et al. 2016). It has come out that numerous ecosystem elements and processes can be affected by salvage logging, such as soil composition and erodibility (Kishchuk et al. 2015, Wagenbrenner et al. 2015), snag availability as nesting sites for birds (Hutto and Gallo 2006), the invasion of alien plant species (Lindenmayer et al. 2017), and many more. However, there is a clear gap in translating these effects to a language understandable by managers, policy makers, and society in general. A symptom of this is that there is barely any mention of the term *ecosystem services* in the literature regarding post-disturbance logging. The lack of a common language between ecologists and managers limits the application of an approach to post-disturbance management that would consider all the benefits provided by the ecosystem in decision-making (also called Ecosystem Approach; Secretariat of the Convention on Biological Diversity 2000). The importance of suitable communication of the value of nature and the application of ecosystem service valuation to management decisions is widely recognized (CBD 2001, Haines-Young and Potschin 2010, Liu et al. 2010, van den Belt and Stevens 2016), yet they are scarcely implemented for non-provisioning services (Boerema et al. 2016) and their absence is especially notorious in the literature regarding salvage logging. Linking the effects of post-disturbance management on ecosystem processes with effects on human welfare is therefore critical to provide a more comprehensive basis for decision-making beyond the simplistic focus on burned-wood revenues.

In this study, we illustrate how ecological processes that are affected by salvage logging can be described under the ecosystem services paradigm in a way as to show the link between the biophysical components of post-disturbance ecosystems and human well-being (Haines-Young and Potschin 2010). We focus on seed dispersal, an ecosystem service that can be affected by post-disturbance management (Rost et al. 2009, Castro et al. 2013, Leverkus et al. 2016). We evaluate the dispersal service provided by the activity of vertebrates, mostly the Eurasian Jay (*Garrulus glandarius* L.), as a mechanism for the natural recovery of native oak forests after fire in three contrasting post-fire logging scenarios. We aim to assess whether salvage logging and two management alternatives generate different value for society due to effects on the capacity for natural regeneration. With this approach, we seek to exemplify how ecologists can provide input to decision-makers that allows bridging the gap with society and managers to enhance the regeneration and conservation of disturbed ecosystems.

Materials and Methods

Methodological framework

Ecosystems and organisms within them contribute to human well-being through ecosystem services (MA 2005). To assess the contribution of an ecosystem service to human welfare, as is our aim in this study, the link between an observable process and its value for society must be clearly identified (Haines-Young and Potschin 2010). This involves linking an element of the ecosystem and a function that it performs (i.e., the biophysical components of an ecosystem service) with the benefits that society obtains and, ultimately, the value placed on

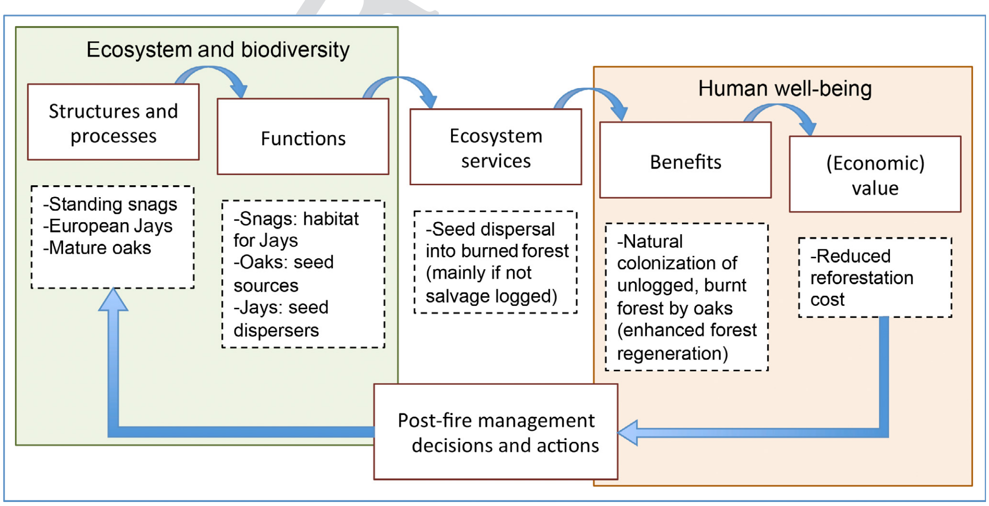

Fig. 1. Ecosystem services cascade illustrating the case of seed dispersal by European jays after fire. Studying ecosystem services from both the ecosystem and the human well-being points of view may aid translating ecological research on post-disturbance logging into direct input for practitioners. Diagram adapted from Haines-Young and Potschin (2010) and Martín-López et al. (2014).

it (i.e., the human well-being component; Fig. 1). Valuations of ecosystem services allow assessing the effects of human interventions to natural capital stocks (Liu et al. 2010).

Although seed dispersal is a major ecosystem service provided by birds and other vertebrates (Whelan et al. 2008), it remains poorly understood and greatly undervalued (Hutchins et al. 1996, Whelan et al. 2008). Through animal-mediated seed dispersal, plant species benefit from gene flow, escape from high-mortality areas, reach more favorable sites, and colonize new or degraded sites (Rost et al. 2009, Cavallero et al. 2013, Andivia et al. 2017). On the human-welfare side of this process, plant natural regeneration mediated by seed dispersal may imply a reduced need for reforestation (Hougner et al. 2006, Puerta-Piñero et al. 2011). Here, we use the ecosystem services framework to assess how post-fire management affects the value for society of the natural regeneration of oaks mediated by seed dispersal by vertebrates, mainly birds, into a burned forest.

Study site and experimental design

This research is based on empirical data on ecological processes leading to oak natural regeneration after post-fire management in three different treatments that include salvage logging (Castro et al. 2012, Leverkus et al. 2016), together with the cost evaluation of reforestation under these three scenarios (Leverkus et al. 2012). The study was conducted after the Lanjarón fire of September 2005, which affected 1300 ha of ~40 yr old, planted pine stands in Sierra Nevada, southern Spain (Castro et al. 2010). The affected pine species are native, although the climax vegetation in the area corresponds to Holm oak (*Quercus ilex* L.) forests (Leverkus et al. 2015). Climate in the area is Mediterranean, with hot, dry summers and mild, wet winters. Six months after the fire, three experimental plots of 18–32 ha were established along an elevational gradient to test the effects of post-fire management on ecosystem regeneration. Each plot comprised nine subplots, which were randomly allocated one of three replicates of one of three burned-wood management treatments (Data S1). The treatments were (1) non-intervention (NI), where no action was taken and the snags remained standing until their collapse 4–6 yr after the fire; (2) partial cut plus lopping (PCL), an intermediate management treatment where 90% of the burned trees were felled but leaving all the biomass in situ; and (3) salvage logging (SL), where the trees were cut, their trunks cleared of branches and manually piled in groups of 10–12, and the woody debris was chopped, thus leaving an open habitat structure.

The area surrounding the study plots was salvage logged, and the local forest service performed a mechanized reforestation in March 2010 (4 yr after the fire) with Holm oaks and other species. The reforestation covered the two higher-elevation plots (described in Leverkus et al. 2012), whereas the lowest-elevation plot (described in Leverkus et al. 2016) was not reforested and was reserved to study natural regeneration (Data S1). The cost of reforestation was calculated for each subplot by the local Forest Service (for details, see Leverkus et al. 2012). We monitored seedling survival two growing seasons after planting, which allowed calculating reforestation costs per live seedling.

Oak natural regeneration

Holm oak natural regeneration was studied at the lower elevation plot. Holm oak regeneration can occur either by resprouting of existing individuals or by seed germination. Acorns are dispersed by animal vectors, which in the study area are mostly rodents (e.g., wood mice) and Eurasian Jays, a scatter-hoarding corvid. Acorn dispersal into the pine stand (and thus oak regeneration) likely began decades before the fire. In the study plot, there was an intense regeneration after the fire, which could be ascribed to pre-treatment and post-treatment scenarios (Leverkus et al. 2016).

As pre-treatment regeneration we considered all the oak individuals that appeared after the fire, in the spring of 2006, and that had a height below 35 cm. They corresponded mostly to resprouts (~~author's~~, *personal observation*), although some of them could have been the result of the germination of an acorn dispersed into the experimental plot just after the fire, in the autumn of 2005, yet before the implementation of post-fire treatments. We could not distinguish those two categories unequivocally, yet both represent regeneration that occurred before treatment implementation. Pre-treatment oaks were likely the result of the ecosystem service of seed dispersal across many years previous to the fire, although their origin is not certain. In any case, as the treatments did not exist at the time of establishment of the pre-treatment seedlings, we calculated the value of the ecosystem service at the plot level.

As post-treatment regeneration we considered seedlings that recruited in the 6 yr after treatment implementation, beginning in spring 2007. These seedlings were the result of establishment from acorns dispersed from nearby seed sources once the treatments existed (Leverkus et al. 2016). A previous study demonstrated that Jays still used the standing burned trees (i.e., the NI treatment) as a habitat type to cache acorns, whereas they avoided areas devoid of burned trees (Castro et al. 2012). It is very likely that, in our case, Jays were the only dispersers of acorns given the distance between the experimental plot and the nearest Holm oak patches (see Leverkus et al. [2016] for details). Seed dispersal leading to post-treatment regeneration represents an ecosystem service provided after treatment implementation, and we thus report its magnitude for each experimental treatment. The final numbers of surviving seedlings/saplings were assessed 7 yr after the fire in each replicate of each post-fire treatment (Leverkus et al. 2016).

Economic valuation of the ecosystem service

We valued the provision of the ecosystem service of oak natural regeneration in the three post-fire wood management treatments. We used the replacement cost (RC) method to estimate the economic value of post-fire natural regeneration as the cost of planting nursery-grown seedlings instead. The density of seedlings that naturally established and were still recorded alive in 2012 was multiplied by the empirically obtained cost of ~~planting to~~ obtain one live seedling. For a description and justification of the RC method and detailed methods, see Appendix S1.

Results and Discussion

The ecosystem service of oak natural regeneration was worth between tens and over one hundred euros per ha, depending on the timing of recruitment (previous or subsequent to the implementation of post-fire treatments) and, in the case of post-treatment seedlings, on the post-fire management strategy employed (Table 1). This value resulted from the avoided cost of reforestation due to acorn dispersal by vertebrates (most likely Jays) and the resprouting capacity of oaks (Hougner et al. 2006, Puerta-Piñero et al. 2011) and ultimately from the accumulated ecosystem service of seed dispersal provided by animals. Despite the relatively small magnitudes of the economic values, this study case exemplifies the potential of translating the results of ecological research into direct input for managers if the ecological processes are linked with human well-being via the ecosystem services framework (Fig. 1).

In the case of post-management seedlings, we can ascribe recruitment with precision to post-disturbance acorn dispersal (Castro et al. 2012). Although the economic value of this ecosystem service was relatively small, it showed variation across treatments: the non-intervention areas provided about twice the value of the treatments where the burned logs were felled (Table 1). This can be explained by the positive habitat selection by Jays of standing trees, even if burned (Castro et al. 2010, 2012). Our results therefore show that acorn dispersers provided a valuable ecosystem service if burned trees were not salvaged.

The seedlings that recruited before treatment implementation, which likely comprised mainly resprouting individuals recruited before the fire, provided the greatest economic value (Table 1). Resprouting is ~~indeed~~ one of the main post-fire regeneration strategies of plants in the Mediterranean Basin (Pausas et al. 2004), a trait that enhances ecosystem resilience to disturbance and provides direct value to society due to the reduced cost of reforestation (Hougner et al. 2006). Our study shows that the value of the ecosystem service of natural regeneration of oaks in disturbed, salvage-logged areas may depend almost exclusively on resprouting oaks that happen to be on site. While the value of natural regeneration in non-intervention areas was also lower than that of pre-management recruitment (Table 1), it should be noted that recruitment in salvage logged subplots ceased almost immediately after the fire, whereas this ecosystem service in non-intervention areas is an ongoing process that can be expected to perpetuate at least as long as the snags remain standing (Leverkus et al. 2016).

The ecosystem service of Holm oak regeneration matters for several reasons. The Holm oak is the most relevant native forest-forming tree species in the area (Valle 2003), and the forests it forms are a major conservation and restoration target in both Spanish and European regulations (e.g., EEC Regulation no. 2080/92; Rodà et al. 2009, WWF 2011). However, the assisted regeneration of Holm oak forests has largely failed. Most of the available studies document high rates of seedling mortality after ~~artificial~~ regeneration (e.g., Rey Benayas et al. 2005, Valdecantos et al. 2006), so that the demand for the ecosystem service of Holm oak natural regeneration is guaranteed. Natural regeneration in this study rendered oak densities that may be considered low, yet they

Table 1. Seedling densities and economic value of oak natural regeneration across the post-fire treatments.

	Pre-management†		Post-management‡		Savings (€/ha)§	
Treatment	No. individuals	Density (no./ha)	No. individuals	Density (no./ha)	Pre-management†	Post-management‡
Non-intervention	—	—	15.3 ± 5.7	8.5 ± 3.3	—	36.2 ± 15.0
Salvage logging	—	—	4.7 ± 3.7	3.7 ± 3.2	—	15.8 ± 13.9
Partial cut plus lopping	—	—	7.7 ± 2.4	3.9 ± 0.8	—	16.6 ± 4.2
Whole plot~~§~~	46.7 ± 16.4	26.9 ± 9.3	9.2 ± 2.6	5.4 ± 1.6	114.5 ± 43.0	23.0 ± 7.6

Note: All values are means ± SE between subplots (n = 3 for treatments; n = 9 for whole plot).

†Recruited either before the fire or from acorns dispersed between the fire and treatment implementation (i.e., up to 2006); values are thus reported as averages of the whole plot, independently of treatments.

‡Recruited after the creation of the post-fire treatments (i.e., between 2007 and 2011), most likely as a result of seed dispersal by Jays; values are reported per treatment and as a whole-plot average (pooling treatments).

§Based on a cost of reforestation of €4.26 ± 0.62 per seedling, empirically obtained for reforestation performed in 2010. See Appendix S1 for details.

still constitute an acceptable starting point for these, often savannah-like, forests (Rodà et al. 2009). The scattered established trees will constitute seed-producing islets from which the surroundings will later be colonized (Rey Benayas et al. 2008). Our results thus support that the commonly applied regime of post-disturbance salvage logging could have negative consequences for the regeneration of forest vegetation (Donato et al. 2006, Macdonald 2007, Marzano et al. 2013, Brown et al. 2014, Leverkus et al. 2014, but see Royo et al. 2016) and reduce the value of the ecosystem service of natural regeneration by increasing reforestation needs.

The results here obtained can be added to the economic balance of the direct cost of the three analyzed management options. Salvage logging resulted in direct losses of >2000 €/ha to the Forest Service after accounting for logging operations and the extraction, transportation, and sale of the burned wood (Leverkus et al. 2012). In fact, the revenue from timber sales roughly covered the cost of extraction and transportation of the wood. This is a common outcome in young Mediterranean pine stands on public lands (e.g., in national parks such as Sierra Nevada) whose management does not follow strict economic purposes (Velasco and Hernández 2012), and it contrasts with other parts of the world where burned trees are generally salvaged for the economic revenue (Lindenmayer et al. 2008). In either case, the inclusion of the value of oak natural regeneration in the cost–benefit analysis could reveal changes to this balance: at sites where post-fire seed dispersal is favored due to the presence of seed dispersers and nearby seed sources, non-intervention approaches would not only lack a direct management cost (other than the case-specific opportunity cost of timber) but also provide an indirect value through the savings from the reduced need of reforestation.

Conclusions

Besides *salvaging* the value of timber, salvage logging can affect many other ecosystem services, such as seed dispersal, nutrient cycling, water retention, carbon absorption, habitat provision, and many others (McIver and Starr 2000, Lindenmayer et al. 2008, 2017, Peterson et al. 2009, Serrano-Ortiz et al. 2011). These, in turn, should be balanced with the economic returns from timber to make better-informed decisions on post-fire management. Methodological frameworks such as the Toolkit for Ecosystem Service Site-based Assessment (Peh 2013) may prove useful to assess an array of different ecosystem services under different management scenarios and provide advice as to what ecosystem service trade-offs would occur between alternative post-disturbance management schemes. We therefore call for a holistic, ecosystem services approach in ecological research to bridge the gap between science and policy regarding post-disturbance management.

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Supporting Information

Additional supporting information may be found online at: http://onlinelibrary.wiley.com/doi/10.1002/eap.1539/full

Data Availability

Data associated with this paper are available in the Dataverse institutional repository of the University of Alcalá https://doi.org/10.21950/wavfnr

Communications

Author Query Form

Journal: EAP
Article: 1539

Dear Author,
During the copy-editing of your paper, the following queries arose. Please respond to these by marking up your proofs with the necessary changes/additions. Please write your answers on the query sheet if there is insufficient space on the page proofs. Please write clearly and follow the conventions shown on the attached corrections sheet. If returning the proof by fax do not write too close to the paper's edge. Please remember that illegible mark-ups may delay publication.
Many thanks for your assistance.

Query reference	Query	Remarks
1	AUTHOR: Please confirm that given names (red) and surnames/family names (green) have been identified correctly.	Correct
2	AUTHOR: CBD 2001 has not been included in the Reference List, please supply full publication details.	
3	AUTHOR: van den Belt & Stevens 2016 has not been included in the Reference List, please supply full publication details.	
4	AUTHOR: Please replace “author’s” with first initial and surname of the author(s) making the observation.	
5	AUTHOR: Please explain the meaning of cells with dashes in them. If they just mean that treatment did not exist for that parameter, please leave the cells empty.	
6	AUTHOR: Please provide the publisher location for reference Haines-Young and Potschin (2010).	
7	AUTHOR: Lindenmayer and Noss (2006) has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List.	
8	AUTHOR: Lundberg and Moberg (2003) has not been cited in the text. Please indicate where it should be cited; or delete from the Reference List.	
9	AUTHOR: Please provide the publisher’s location (city, state, country) for Peterson et al. 2009.	
10	AUTHOR: Please provide the page range and spell out the editor’s name for reference Rodà et al. (2009).	
11	AUTHOR: Please provide the publisher location for reference Secretariat of the Convention on Biological Diversity (2000).	
12	AUTHOR: Please provide the volume number, page range for reference Thom and Seidl (2015).	
13	AUTHOR: Please spell out WWF and provide the publisher’s name and location for WWF 2011.	

MARKED PROOF

Please correct and return this set

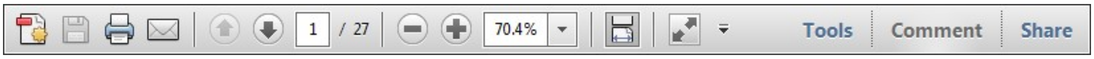
Please use the proof correction marks shown below for all alterations and corrections. If you wish to return your proof by fax you should ensure that all amendments are written clearly in dark ink and are made well within the page margins.

Instruction to printer	*Textual mark*	*Marginal mark*
Leave unchanged	· · · under matter to remain	Ⓥ
Insert in text the matter indicated in the margin	⋏	New matter followed by ⋏ or ⋏ⓧ2
Delete	/ through single character, rule or underline or ⊢⊣ through all characters to be deleted	∂ or ∂ⓧ2
Substitute character or substitute part of one or more word(s)	/ through letter or ⊢⊣ through characters	new character / or new characters /
Change to italics	— under matter to be changed	⌐
Change to capitals	≡ under matter to be changed	≡
Change to small capitals	= under matter to be changed	=
Change to bold type	~ under matter to be changed	~
Change to bold italic	≂ under matter to be changed	≂
Change to lower case	Encircle matter to be changed	≢
Change italic to upright type	(As above)	⊹
Change bold to non-bold type	(As above)	⊹
Insert 'superior' character	/ through character or ⋏ where required	Y or ⋏ under character e.g. Y or ⋏
Insert 'inferior' character	(As above)	⋏ over character e.g. ⋏
Insert full stop	(As above)	⊙
Insert comma	(As above)	,
Insert single quotation marks	(As above)	Y or ⋏ and/or Y or ⋏
Insert double quotation marks	(As above)	Y or ⋏ and/or Y or ⋏
Insert hyphen	(As above)	⊢⊣
Start new paragraph	⌐	⌐
No new paragraph	↩	↩
Transpose	⊔⊓	⊔⊓
Close up	linking ⁐ characters	⁐
Insert or substitute space between characters or words	/ through character or ⋏ where required	Y
Reduce space between characters or words	| between characters or words affected	⊤

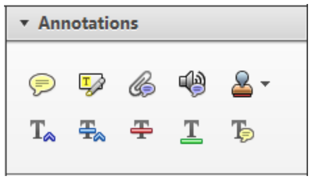
USING e-ANNOTATION TOOLS FOR ELECTRONIC PROOF CORRECTION

WILEY

Once you have Acrobat Reader open on your computer, click on the Comment tab at the right of the toolbar:



This will open up a panel down the right side of the document. The majority of tools you will use for annotating your proof will be in the Annotations section, pictured opposite. We've picked out some of these tools below:

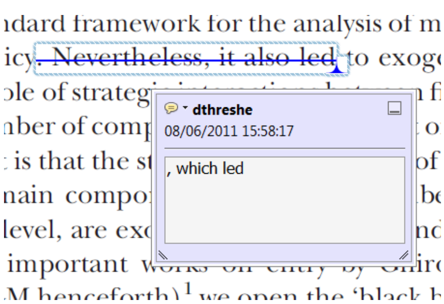


1. Replace (Ins) Tool – for replacing text.

Strikes a line through text and opens up a text box where replacement text can be entered.

How to use it

- Highlight a word or sentence.
- Click on the Replace (Ins) icon in the Annotations section.
- Type the replacement text into the blue box that appears.

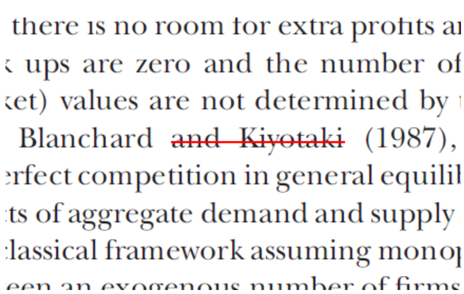


2. Strikethrough (Del) Tool – for deleting text.

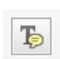
Strikes a red line through text that is to be deleted.

How to use it

- Highlight a word or sentence.
- Click on the Strikethrough (Del) icon in the Annotations section.



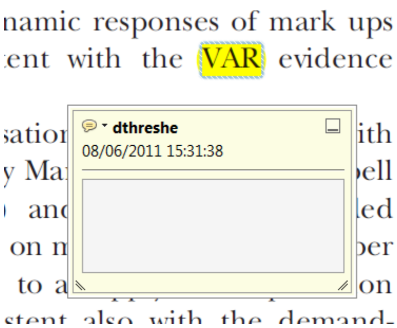
3. Add note to text Tool – for highlighting a section to be changed to bold or italic.



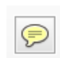
Highlights text in yellow and opens up a text box where comments can be entered.

How to use it

- Highlight the relevant section of text.
- Click on the Add note to text icon in the Annotations section.
- Type instruction on what should be changed regarding the text into the yellow box that appears.



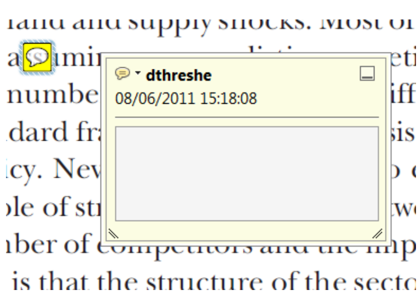
4. Add sticky note Tool – for making notes at specific points in the text.



Marks a point in the proof where a comment needs to be highlighted.

How to use it

- Click on the Add sticky note icon in the Annotations section.
- Click at the point in the proof where the comment should be inserted.
- Type the comment into the yellow box that appears.

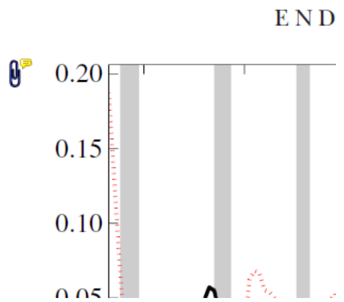


5. Attach File Tool – for inserting large amounts of text or replacement figures.

Inserts an icon linking to the attached file in the appropriate place in the text.

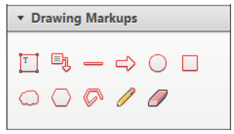
How to use it

- Click on the Attach File icon in the Annotations section.
- Click on the proof to where you'd like the attached file to be linked.
- Select the file to be attached from your computer or network.
- Select the colour and type of icon that will appear in the proof. Click OK.



6. Drawing Markups Tools – for drawing shapes, lines and freeform annotations on proofs and commenting on these marks.

Allows shapes, lines and freeform annotations to be drawn on proofs and for comment to be made on these marks.



How to use it

- Click on one of the shapes in the Drawing Markups section.
- Click on the proof at the relevant point and draw the selected shape with the cursor.
- To add a comment to the drawn shape, move the cursor over the shape until an arrowhead appears.
- Double click on the shape and type any text in the red box that appears.