The Effect of Focal Length on Perception of Scale and Depth in Landscape Photographs

Implications for visualisation standards for wind energy developments

Final Report

17 May 2012

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1 EXECUTIVE SUMMARY

1.1 Background

1.1.1 In January 2010, The Highland Council published detailed and prescriptive standards for the production of visualisations for the visual impact assessment (VIA) of proposed wind energy developments. The purpose of this study was to independently field test and verify The Highland Council's visualisation standards. It was also anticipated that the results obtained would contribute to the future revisions of the standards as necessary.

1.1.2 In the course of this study, interviews were conducted with over 500 members of the public during the preliminary pilot investigation and the subsequent main survey (n=346) between June and November 2011. The participants were recruited at 6 viewpoints located in the Central and Highland regions of Scotland.

1.1.3 The participants were shown single frame A3 photographs of the surrounding landscape at 7 different focal lengths (50mm, 60mm, 70mm, 80mm, 90mm, 100mm and 110mm) and asked to specify which of the images, in their opinion, provided the most realistic representation of the scale and distance to a specific focal point (or area) located centrally in the landscape in all photographs.

1.2 Main findings

1.2.1 The focal length considered by the public as that providing the most realistic representation of landscape scale varied markedly between participants and to a lesser extent between different viewpoints. However, the vast majority of participants in the main survey (n=334; 96.5% of the sample) were of the opinion that a 50mm single frame image for visualisation made the specified focal point (or area) appear too small and too far away relative to its appearance in the actual landscape.

1.2.2 The focal length most frequently specified by participants as that providing the most realistic representation of landscape scale and distance was the 70mm photograph (n=82; 23.7%) although an almost identical number of participants chose the 80mm photograph (n=81; 23.4%). These findings were broadly consistent across all the landscape views considered during the study with one exception where the public more frequently selected the 90mm image.

1.2.3 The distribution of focal length preferences was slightly skewed towards the longer focal lengths considered in the study. Hence, the mean focal length calculated from the participants' responses was 79.3mm (±1.58mm) for all responses obtained. This ranged between 75.3mm (±4.96mm) and 89.5mm (±3.88mm) for individual landscape views. The median of all participant responses was 80mm, but this ranged between 70mm and 90mm depending on the view under consideration.

1.2.4 The participants' choice of focal length did not demonstrate a clear and systematic relationship with the distance to the focal point under consideration in the landscape but this warrants further investigation. It was noted, however, that the way in which the images are viewed has a significant effect on perceptions of landscape scale.

1.3 Conclusions

1.3.1 The results suggest that images produced at a focal length of between 70mm and 80mm generally provide the most realistic representations of landscape scale and depth at least for the type of views considered during this study.

1.3.2 The use of a single frame image produced at a 75mm focal length is therefore considered to be broadly appropriate for wind farm visualisation and that most likely to be acceptable to the largest proportion of the public. The prescription of a single focal length standard also has the advantage of simplicity and clarity for applicants.

1.3.3 The use of alternative images produced at focal lengths shorter or longer than 75mm might be appropriate in very specific circumstances depending on the landscape context under consideration.

1.4 Recommendations

1.4.1 On the basis of the results obtained in this study, the following recommendations are made in relation to standards for the visualisation of wind energy developments.

- Single frame images produced at a 75mm focal length should be used for wind farm visualisation in most circumstances. The use of an additional image produced at a 50mm focal length is unnecessary.
- The specification of a 75mm focal length for visualisations should be accompanied by a caveat that alternative images at shorter or longer focal lengths might be required for some views at the discretion of the planning authority.
- The provision of visualisations for use by professionals and members of the general public should always be accompanied by detailed and precise instruction not only on the intended purpose of the visuals but also how the images should be correctly viewed.

CONTENTS

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ACKNOWLEDGEMENTS

In addition to the named authors the following are acknowledged as having contributed to the study described in this report:

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Gordon Mooney	(formerly of) The Highland Council
Alan Macdonald	Architech Animation Studios
Roger Watt	University of Stirling
Cheryl Rafferty	University of Stirling
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This report should be cited as:

Hunter, P.D. and Livingstone, D.F. (2012) The effect of focal length on perceptions of scale and depth in landscape photographs. Implications for visualisation standards for wind energy developments. Final Report to The Highland Council, University of Stirling.

2 BACKGROUND

2.1. Visual Impact Assessment

2.1.1 In the last two decades, as part of the UK commitment to reduce carbon gas emissions, there has been a marked shift in energy policy towards the use of renewables. The Scottish Government has set a target of generating 100% of Scotland's electricity from renewable sources by 2020. This ambitious aim has already seen a rapid expansion in on-shore wind energy and this is a trend likely to continue for the foreseeable future. This expansion in on-shore wind energy will undoubtedly alter Scotland's landscape. It is perhaps not unsurprising that one of the most common objections to applications for new wind energy developments is on the grounds of the perceived visual impact on the landscape and people.

2.1.2 Applicants submitting proposals for most new on-shore wind energy developments in Scotland carry out an Environmental Impact Assessment (EIA). This normally includes a requirement to undertake a Landscape and Visual Impact Assessment (LVIA). LVIA is the methodical professional process through which the impact of a proposed development on the landscape and visual resource is assessed.

2.1.3 Visual Impact Assessment (VIA) is considered to be a subset of the LVIA process and can be broadly defined as the systematic assessment of the likely change (positive or negative) in the visual resource of the landscape resulting from a proposed development. The assessment of visual impact, as it is essentially concerned with human perceptions of landscape change, is therefore a largely qualitative process reliant on the judgements of stakeholders involved in the planning process, including landscape professionals, but importantly also a wider public audience.

2.1.4 To inform the VIA process it is commonplace for developers to submit visualisations that attempt to illustrate how an observer's view of the landscape from one or more selected viewpoints might be impacted by the proposed development. These visualisations can include computer generated wireframe (or wireline) models as well as single frame and panoramic photographs and photomontages. The use of wireframe models in the field by landscape professionals and planners is widely accepted (University of Newcastle, 2002). The use of photographic images is, however, somewhat more controversial because it is often perceived that such visuals do not accurately portray the likely visual impact of a development on the landscape although the use of photographic images is the only practical method available for visualisation that can be readily accessed by members of the public and decision makers.

2.1.5 The current *Visual Representation of Windfarms Good Practice Guidance* published by Scottish Natural Heritage (SNH, 2006) is the recommended guidance on the production of visualisations for landscape professionals. As far as the use of photography is concerned, the SNH (2006) guidance suggests the use of a 50mm lens on a 35mm format camera as the base photographic standard for all photography used for windfarm VIA including single frame images, panoramas and photomontages. The use of longer telephoto lenses is indicated as being useful only in '*very specific circumstances*' where the windfarm is located in the very far distance and a telephoto lens may help compensate for the lack of '*shade differentiation*'.

2.1.6 The suggested used of a 50mm lens on a 35mm camera for all photography for VIA stems from the widely held view that this format closely replicates what is seen by the human eye. The SNH (2006) guidance suggests the use of single frame visualisations only where the key characteristics of a view and the extent of the proposed development can be framed inside a narrow field of view (≤39 degrees). This format is often disregarded by landscape professionals because it does not show sufficient visual resource. Instead, panoramic images made from horizontally overlapping 50mm single frame images are used to provide a wider field of view. The SNH (2006) guidance has widely informed the requirements for visualisations set out in the scoping advice issued by planning authorities in Scotland and is strongly endorsed in the Landscape Institute Advice Note 01/11. However, photographic visualisations produced according to these recommendations have attracted widespread criticism from the general public who claim that they are often not representative of the vertical landscape scale and the actual visual impact of wind turbines.

2.1.7 In response to continuing complaints from the general public, The Highland Council published its own *Visualisation Standards for Wind Energy Developments* in January 2010 (The Highland Council, 2010) following nearly four years of research and empirical testing. The Highland Council are the first local authority in Scotland to establish detailed and prescriptive standards for wind energy visualisations. The Standards prescribe the use of 50mm single frame images at ten times enlargement size of 360mm x 240 mm on an A3 page and additional images at focal lengths of 70mm for distances up to 1.5km to the development and 75mm for distances longer than 1.5km. While The Highland Council Standards were informed by extensive research and field-testing undertaken internally by the Planning and Development Service they have not, previous to this study, been independently verified through extensive field tests.

2.1.8 The aim of this study was to rigorously field test the existing visualisation standards to verify and where necessary inform the revision of the current Highland Council Standards. In particular, the study sought to establish the most appropriate focal length for photographic visualisations for a range of landscapes considered representative of those often subject to planning applications for proposed wind energy developments.

2.2 Photographic depth perception

2.2.1 There is an extensive literature on human visual perception and also photorealism but a comprehensive discussion on these topics is beyond the scope of this report. The reader is referred to Gregory (1998) and Bruce et al. (1997) for accessible introductions to these topics. Briefly, a number of visual cues are known to inform our perception of depth whether in the real world or in pictorial representations. The foremost means of depth perception is retinal size, which is directly proportional to the actual size of an object and inversely proportional to the viewing distance. Thus objects that subtend a smaller visual angle are perceived as being more distant.

2.2.2 In additional to retinal size, there are a number of other visual cues that inform depth perception of particular relevance to photorealism:

- *Aerial perspective*. This refers to the phenomenon whereby atmospheric scattering results in distant objects appearing hazier than those closer to the observer.
- *Occlusion* (or *interposition*). This refers to the fact that foreground features obscure those towards the back of the sagittal (front-to-back) plane. It provides a relative impression of the distance.
- *Relative height and size*. Objects further away from the horizon are perceived as being nearer to the observer, while larger objects are seen as closer.
- *Linear perspective*. This refers to the phenomenon whereby converging lines in the landscape accentuate the impression of depth.

- *Texture*. This refers to the concept that the texture of objects appears finer and more uniform with increasing distance.

2.2.3 It is important to recognise retinal size alone will not determine individual perceptions of visual impact obtained from landscape photographs but rather this is also likely to be influenced by a complex interplay of one or more of these other visual cues (University of Newcastle 2002). It is also suggested that the phenomenon of size constancy might influence perceptions of visual impact. This refers to the fact that familiar objects are often perceived to be the same size irrespective of the dimensions of the image projected on the retina (Gregory, 1997). While there is currently little evidence that such effects extend to wind turbines, size-constancy might be expected to influence perceptions of visual impact particularly where considerable distances are involved.

2.2.4 While the visual cues that inform depth perception are well understood, little empirical research has specifically focused on photographic representations of depth and how this influences perceptions of scale and distance. In one of the few studies conducted to date, Kraft et al. (1986) examined the effect of focal length on individual perceptions of distance in pictorial images. In this study, perspective was manipulated by photographing a scene at four different focal lengths from extreme wide-angle (17mm) through to normal (48mm). They found that perceived depth in the sagittal plane was inversely related to focal length. That is, short focal lengths made objects appear further away. Interestingly, they note that perceived distance was significantly influenced by changes in foreground extent. However, it should be noted that Kraft et al. (1986) only considered the effect of focal length over very short distances (32m to 614m).

2.2.5 In a subsequent study, Kraft and Green (1989) examined the effect of longer telephoto focal lengths on perceptions of distance in photographs using images taken at 17mm (extreme wide-angle) through to 135mm (telephoto) and at distances ranging from 20m to 320m. They concluded that the photographic field of view significantly influenced depth perception in the sagittal plane. The use of a wide-angle lens led to a consistent overestimation of distance, whereas the telephoto focal lengths led to an underestimation of distance. They also note that the change in the vertical and horizontal field of view as a function of focal length also influences the visual cues available to the observer and this consequently leads to differences in depth perception.

2.2.6 In addition to changes in focal length, pictorial depth can also be influenced by changes in the viewing distance or image size (e.g. Smith and Gruber, 1958; Thompson and Bartley, 1959) although this would seem to be of secondary importance in relation to changes in focal length as shown by Kraft et al. (1986) and Kraft and Green (1989). Other studies have variously examined how preconceptions of body size can influence depth perception (Stefanucci and Geuss, 2009) as well as aspects of landscape character (e.g. Bernaldez et al. 1988).

2.2.7 In a recent study, Takezawa (2011) revisited the effect of retinal size on the perception of distance in photographs. This study was able to demonstrate that perceived absolute distances decrease with changes in retinal size associated with increasing focal length. However, the relationship was not inversely proportional and it is suggested that depth perception is not only a function of retinal size but also its ratio to the overall image size. It must be noted that this study also only considered distances between the observer and the focal object of between 20m and 60m.

2.2.8 There are very few, if any, studies that have considered the perception of size and distance in photographs over much longer distances – i.e. comparable to the distances used for landscape visualisations of wind energy developments. It is not certain whether the factors determining depth perception over very short distances apply equally to photographs of more distant objects. Importantly, this study is therefore one of the first to examine the effect of focal length on the perception of scale and depth in photographic images of landscapes.

3 STUDY METHODS

3.1 Overview

3.1.1 The data presented in this report were compiled from interviews with members of the general public at 6 viewpoints located in the Central and Highland regions of Scotland. Individual participants in the study were shown photographs of specific views of the landscape surrounding each viewpoint at focal lengths ranging from 50mm to 110mm. The participants were instructed to focus on a specific focal point (or area) in each of the photographs and asked to specify the image that provided the most realistic representation of the scale and distance to the focal point within the real landscape. The participants' responses were recorded alongside standard demographic information.

3.2 Pilot study

3.2.1 The University of Stirling undertook initial field tests of the survey methodology with members of the general public in June 2012. These initial field trials were used to develop and rigorously test the methodology for presenting the photographs to respondents and eliciting their focal length preference. This included tests in which participants were presented with the images arranged in order of focal length as well as in a randomised fashion known only to the interviewer.

3.2.2 A decision was made in early course to exclude landscape views containing existing wind energy developments from consideration in the study. This decision was based on a concern that the presence of a wind energy development might bias the responses of participants with predetermined and strongly held views about the visual impact of wind energy developments on the Scottish landscape.

3.2.3 The observations made during the initial field trials informed a formal pilot survey with 51 members of the general public in June and July 2012. Three contrasting views were used during the pilot study: (i) the Wallace Monument as viewed from Stirling Castle Esplanade (2.5 km to focal point); (ii) a low ridge line viewed from the Bannockburn Visitor Centre (2.0 km); and (iii) Beinn Eich viewed across the water from the eastern shore of Loch Lomond (11 km). In the pilot study, participants were presented with photographic images calibrated at nine focal lengths: 28mm, 35mm, 50mm, 70mm, 75mm, 80mm, 85mm, 90mm and 100mm. The participants were also asked to comment on the methodology and, in particular, to express any difficulties experienced in completing the survey. The comments received from the participants in the pilot study were subsequently used to refine the methodology used in the main survey.

3.3 Main survey

3.3.1 The main survey was administered to members of the general public at selected viewpoints in Scotland between August and November 2012. Information on the viewpoints used in the study is detailed further in Section 3.4. The surveys were only undertaken on days with good weather and visibility. Members of the public were recruited at random for participation in the study. It was made clear at all times that participation was entirely voluntary and only individuals fluent in English and with normal or corrected to normal vision were recruited in the study.

3.3.2 Those who agreed to participate were asked to complete a short questionnaire on the realism of landscape photographs. The questionnaire was structured into three main sections. The first section explained the purpose of the study and included a series of questions about the nature and frequency of the participants' visits to the viewpoint. This section also included questions about the participants' eyesight.

3.3.3 In the second part of the survey, participants were shown a series of photographic images of the landscape surrounding the viewpoint at seven different focal lengths. The focal lengths used were 50mm, 60mm, 70mm, 80mm, 90mm, 100mm and 110 mm. The choice of focal lengths used in the main survey was strongly informed by the preliminary results from the pilot survey such that the focal length range used was likely to cover approximately 95% of the expected distribution. This resulted in the exclusion of the 28mm and 35mm focal lengths used in the pilot study. The increment between focal lengths was also set to a constant 10mm to facilitate the selection of images by participants. Figure 1 shows the full set of images used for the view of Beinn Eich from Milarrochy Bay on the eastern shore of Loch Lomond. The 50mm base images for each view (with ≥25 responses) are contained in Appendix I for reference.

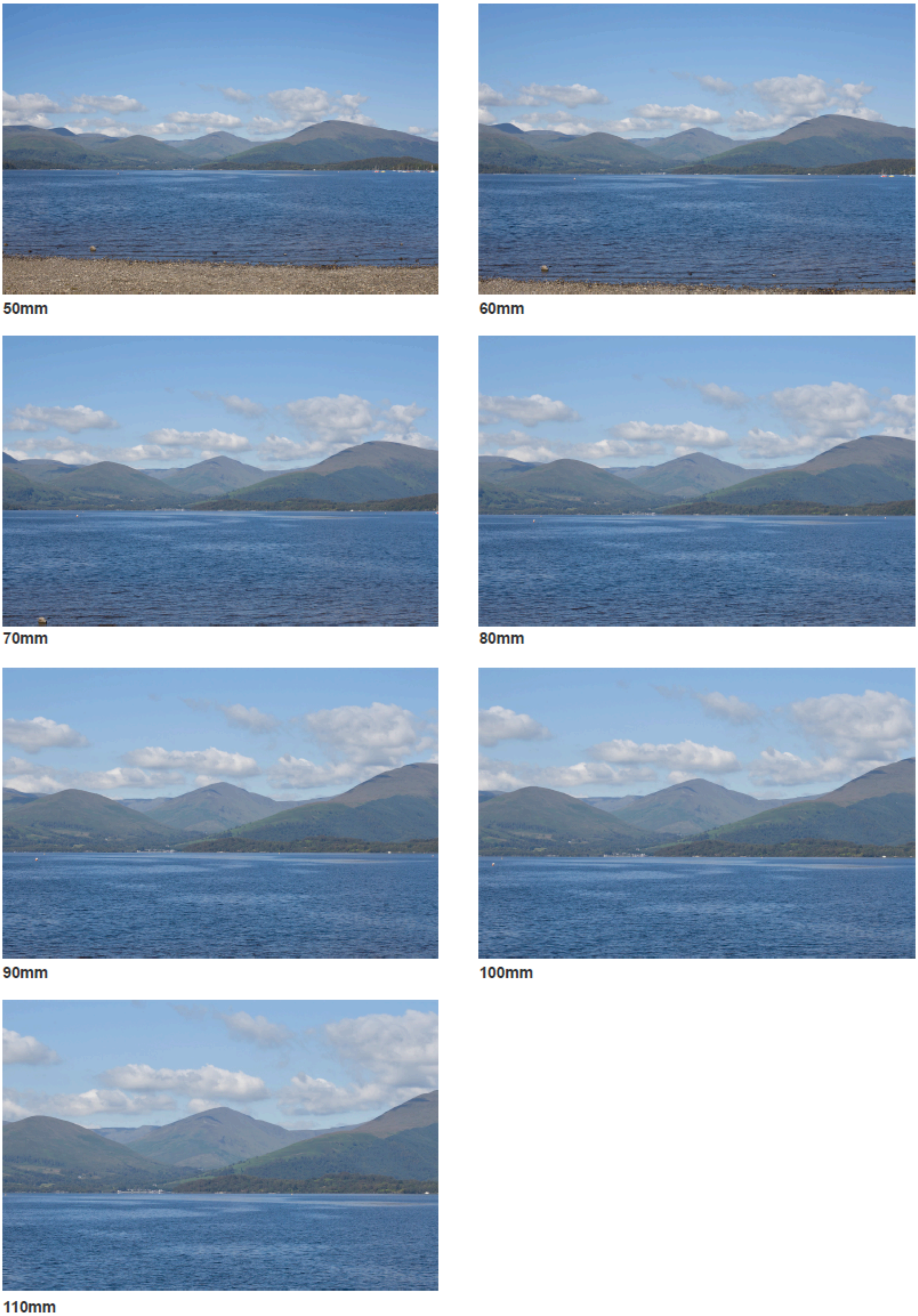

Figure 1. An example of the photographic images used in the study. The view shown is that of Beinn Eich (central focal point in the frame) as seen from the eastern shore of Loch Lomond. The images are presented in order of focal length from 50mm (top left) to 110mm (bottom left).

3.3.4 The photographs used in the study were taken using a fixed 50mm lens on a 35mm format camera, with images at longer focal lengths digitally recalibrated from the 50mm base image (see Appendix II). The photographic images were subsequently printed at an image size of 390mm x 260mm. Further technical detail on the production of the photographic images used in the study is provided in Section 3.5.

3.3.5 The participants were provided with the photographs one at a time and in a randomized order known only to the interviewer. The focal length of each image was not disclosed to the participant. The participants were instructed to concentrate on a specific focal point (or area) clearly visible in both the photograph and the real landscape. The same point of focus in the landscape was used for all photographs irrespective of focal length.

3.3.6 The participants were asked very specifically to consider whether each photograph made the focal point appear: (i) "*too large and too close*"; (ii) "*too small and too far away";* or (iii) at "*about the correct size and distance*" in comparison to the 'real life' view. The interviewer recorded the response for each photographic image in turn. The participants were specifically instructed to base their answers only on how accurately the photographs represented the size of and the distance to the focal point and not on other considerations such as image composition or field of view. The methodology used here is similar to that previously adopted by Kraft et al. (1986) and Kraft and Green (1989) albeit for considerably more distant views.

3.3.7 Preliminary research undertaken during initial field tests prior to the main study revealed that the way in which the participants viewed the photographs had an effect on the responses obtained. Consequently, the participants recruited in main study were given very precise verbal and pictorial instructions as to how the photographic images should be viewed (see Figure 2). This included instruction to hold the board at a "*comfortable and natural distance*" in front of them and in such a manner that the board obscured any foreground detail in the real landscape that was not visible in the photographic image. This stipulation was based in part upon recommendations made in University of Newcastle (2002) and SNH (2006).

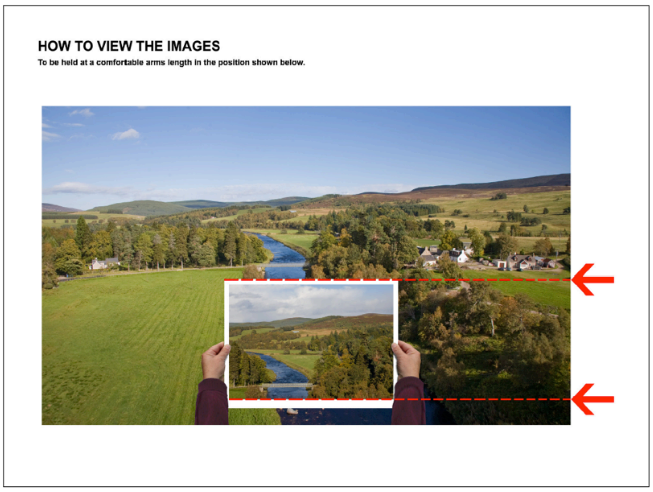

Figure 2. The pictorial instruction provided to participants on the correct methodology for viewing the images. Participants were instructed to hold the image boards at a natural and comfortable distance and in such a way that the image itself obscures any foreground detail not visible in the photograph itself.

3.3.8 The third section of the questionnaire comprised standard demographic questions. The participants were finally asked to review their responses to the survey and approve and endorse the completed questionnaire for purposes of authentication. On average, the participants took between 4 and 5 minutes to complete the questionnaire in full.

3.4 Viewpoint selection

3.4.1 The selection of viewpoints for inclusion in the study was based on a number of criteria. This included the requirement that the viewpoints collectively provided:

- views of a variety of different landscape types with a range of distances to potential focal points or areas
- places where a wide cross section of the public might be expected to congregate and could be easily recruited for participation in the study
- places where the survey could be conducted in an unobtrusive manner and where permission could be obtained from the relevant authorities

3.4.2 The final selection of viewpoints was made in consultation with The Highland Council. The viewpoints used in the main survey were considered to provide views of landscapes experienced throughout Scotland and broadly representative of the type often featured in visualisations for proposed wind energy developments. The full list of viewpoints used in the main survey is provided in Table 1; note that for some viewpoints, more than one focal point in the landscape was considered during the course of the study (although for reasons outlined in Section 4.1 not all views had an equal number of responses).

3.5 Photography

3.5.1 The photography used in the pilot and main study was undertaken professionally by Architech Animation Studios on the 9th and 14th June with some additional shots taken on 13th July 2011. Architech Animation Studios have extensive experience in the production of visualisations for wind energy developments. The photographs were all taken in good weather conditions; this was particularly important in the case of the views to distant focal points where high visibility was essential.

3.5.2 The camera used for all the photography was a tripod mounted 35mm format Canon EOS-5D II camera body with a full frame sensor and a fixed 50mm Canon lens (f1.4) or 28mm Canon lens (f1.8). All photographs were taken as single frame RAW data images complete with appropriate metadata. The camera height above the ground was 1.5m. All base images were taken with a 50mm fixed lens and, for the pilot study only, a 28mm wide-angle lens.

3.5.3 The camera images were framed so that the points (or areas) of focus were contained within the central part of the photographs. The photographs were also framed to take account of the recalibration required for increased focal lengths and in some instances by taking additional frames where the horizon line was adjusted to maintain the balance in images at the longer focal lengths.

3.5.4 The 28mm and 50mm photographs taken with a fixed lens were used to digitally recalibrate the images at other focal lengths. The 35mm focal length used in the pilot study was digitally recalibrated from the 28mm photograph. The remaining images were digitally recalibrated from the 50mm photograph. The recalibration was performed using 3D Studio MAX (Autodesk®, CA). The focal lengths of the resulting photographs were accurate to three decimal places and all images conformed to the horizontal, vertical and diagonal fields of view characteristic of the 35mm format camera. The University of Stirling and a representative of the Highland Council visited Architech's studios in August 2011 to witness and verify the procedure for focal length recalibration.

Table 1. Descriptive summary of the viewpoints and views used in the survey and the approximate distances to the central focal point in each set of photographic images.

Viewpoint	Position	Direction	View	Focal point or area	Distance (km)
Stirling Castle	Esplanade	East	Townscape view to hills beyond	Southern slopes of Dumyat	5.5
				Wallace Monument	2.5
	Queen's Garden	West	Open flat farmland to distant hill ridge	Falleninch Farm	1.2
				Gargunnock ridge	10.4
				Ben Ledi	16.8
				Ben Lomond	43.0
Bannockburn	South of monument	South	Small scale rolling landscape to low ridge line	Telephone mast on ridge line	2.0
	North of monument	North	Framed view of Stirling Castle	Stirling Castle	3.36
Milarrochy Bay	West Highland Way	East	Open view across water to mountains	Beinn Eich	11
David Marshall Forest Lodge	Café viewpoint	South east	Large expansive scenic view to distant hills	Dumgoyne	19.0
				Meikle Bin	24.0
Urquhart Castle	Entrance to castle precinct	South east	Step loch-side ridge with close foreground ruin	Castle ruin	0.18
				Southern ridge line	4.55
	South west tower	North east	Across water to hill ridge	White house at Temple Pier	1.40
				Creag Nay Hill	2.55
Lochindorb	North end of loch	South	Highland moorland loch framed by distant hills	Lochindorb Castle	1.11
				Central hill ridge	8.5

3.5.5 The photographs were printed to a resolution of 300dpi (dots per inch) at an image size of 390mm x 260mm on gloss photo-quality paper and laminated with a matt protective surface mounted on 5mm foam board. The 390mm x 260mm photographic prints used in this study were slightly larger than that recommended in The Highland Council standards (The Highland Council, 2010). However, it is the intention of The Highland Council to increase the image size stipulated in the current standards to the larger 390mm x 260mm format to reduce the extent of the white border on the A3 print and consequently this was adopted as the image size in this study.

3.6 Interviewer bias

3.6.1 It is recognised that interviewer bias can be a significant source of error in questionnaire-based studies (e.g. Dijkstra, 1983). Interviewer bias can arise simply because of the way a particular interviewer poses questions and elicits responses from participants. To test for potential interviewer bias in this study we undertook a further 41 interviews with members of the general public using five independent interviewers. The interviews were undertaken using the view from Stirling Castle Esplanade to Dumyat and the same questionnaire and photography was used as for the main survey. The interviewers were recruited from and independently trained in the administration of the survey by the University of Stirling. They received no instruction from the main interviewer used in the study before undertaking the interviews. The responses from the five interviewers were collated and compared against those of the main interviewer to test for potential bias.

4 RESULTS

4.1 Survey responses

4.1.1 The total number of interviews conducted during the study was 504 including the initial field tests and pilot study. The number of usable survey responses collected during the main survey was 346 with a further 41 responses collected by an independent team of interviewers. Incomplete responses were discarded to avoid item nonresponse bias. The number of responses collected for each viewpoint varied between 8 (Lochindorb) and 139 (Stirling Castle), with the number of responses for individual views ranging between 2 (view to Ben Lomond from Stirling Castle) and 61 (Fallennich Farm from Stirling Castle). This variability in the number of responses largely reflects the number of potential participants encountered at the individual viewpoints used in the study and the fact that some of the longer distance views could only be used on days with very good visibility. The low number of responses obtained at Lochindorb reflects the fact the surveys here were conducted outside the main tourist season and also that there is no single point where the public congregate.

4.2 Participant demographics

4.2.1 The demographic characteristics of the participants varied markedly between the viewpoints (see Table 2). The majority of participants (56.1%) in the survey were visiting the viewpoints from other parts of the UK but the sample also included a significant number of international visitors (36.7%). The number of participants describing themselves as local residents was very low (7.2%) but this reflects the fact the majority of viewpoints used in the study were, by necessity, primarily tourist locations.

4.2.2 The demographic characteristics of the sample were also somewhat variable between viewpoints. The participants at the Urquhart Castle viewpoint were, for example, predominately international visitors whereas those sampled at Millarrochy Bay were largely visitors from the UK. The sex distribution of the full sample showed a slight selection bias towards female participants (54%) but this also varied between the various viewpoints. The average age of respondents for the full sample was 41.6 years but this again varied from an average age of 39.0 years at David Marshall Forest Lodge to 49.3 years at Bannockburn Heritage Centre.

Table 2. Summary of the demographic characteristics of participants for individual viewpoints and the full survey. Numbers in parentheses are percentage of sample.

Viewpoint	n	Local residents	UK visitors	International visitors	Males	Females	Average age (years)
Stirling Castle	139	7 (5.0)	86 (61.9)	46 (33.1)	70 (50.4)	69 (49.6)	39.3
Bannockburn	41	5 (12.2)	19 (46.3)	17 (41.5)	19 (46.3)	22 (53.7)	49.3
Milarrochy Bay	29	4 (13.8)	22 (75.9)	3 (10.3)	16 (55.2)	13 (44.8)	39.6
David Marshall Forest Lodge	37	1 (2.7)	30 (81.1)	6 (16.2)	21 (56.8)	16 (43.2)	39.0
Urquhart Castle	92	7 (7.6)	30 (32.6)	55 (59.8)	30 (32.6)	62 (67.4)	42.8
Lochindorb	8	1 (12.5)	7 (87.5)	0 (0.0)	3 (37.5)	5 (62.5)	46.9
All viewpoints	346	25 (7.2)	194 (56.1)	127 (36.7)	159 (46.0)	187 (54.0)	41.6

4.3 Focal length selection

4.3.1 The focal lengths selected by participants as providing the most realistic representation of the scale and distance in the landscape photographs are summarised in Table 3 and the resulting histograms are plotted in Figure 3. The responses have been analysed for all views and also for individual views with ≥25 responses. It is notable that for the aggregated results from all views less than 5% of participants were of the opinion that the 50mm focal length provided the most realistic representation of the scale and distance to the focal point in the landscape of those images viewed.

Table 3. The frequency of focal lengths chosen by participants as providing the most realistic representation of scale and distance in the landscape for selected views (n≥25) and the full sample.

View	n	Focal length (mm)						
		50	**60**	**70**	**80**	**90**	**100**	**110**
Beinn Eich	29	1 (3.45)	3 (10.3)	9 (31.0)	7 (24.1)	6 (20.7)	2 (6.90)	1 (3.45)
Falleninch Farm	61	2 (3.28)	10 (16.4)	15 (24.6)	14 (23.0)	14 (23.0)	3 (4.92)	3 (4.92)
Gargunnock Hills	51	1 (1.96)	10 (19.6)	14 (27.5)	15 (29.4)	6 (11.8)	3 (5.88)	2 (3.92)
Meikle Bin	29	1 (3.45)	1 (3.45)	2 (6.90)	9 (31.0)	11 (37.9)	5 (17.2)	0 (0.00)
South Ridge Line	40	3 (7.50)	8 (20.0)	12 (30.0)	5 (12.5)	8 (20.0)	2 (5.00)	2 (5.00)
Stirling Castle	36	2 (5.56)	5 (13.9)	7 (19.4)	8 (22.2)	5 (13.9)	7 (19.4)	2 (5.56)
White House	40	0 (0.00)	0 (0.00)	5 (12.5)	11 (27.5)	11 (27.5)	8 (20.0)	5 (12.5)
All	346	12 (3.47)	49 (13.3)	82 (23.7)	81 (23.4)	70 (20.2)	35 (10.1)	17 (4.91)

4.3.2 This trend was generally repeated at all individual viewpoints (n≥25) with only a small increase in the number of participants (7.5%) selecting the 50mm photograph of the view for the South Ridge Line from Urquhart Castle. It is notable that the distribution of focal lengths selected by participants was highly variable; for most views the chosen focal lengths encompassed the full range (50mm-110mm) used in the study. There was no absolute consensus on which focal length(s) provided the most realistic representation of scale and distance for either the full sample or for individual viewpoints. However, the aggregated results from all views show that the most frequently selected focal length was 70mm (23.7% of participants) with an almost identical number of participants also selecting the 80mm focal length (23.4%).

Table 4. Summary statistics of focal lengths chosen by participants as providing the most realistic representation of scale and distance in the landscape for selected views (n≥25) and the full sample. StDev (Standard Deviation); CoefVar (Coefficient of Variation).

View	n	Mean	SE Mean	StDev	CoefVar	Min	Median	Max	Range	Mode
Beinn Eich	29	78.3	2.53	13.7	17.4	50	80	110	60	70
Falleninch Farm	61	78.0	1.84	14.4	18.4	50	80	110	60	70
Gargunnock Hills	51	76.3	1.90	13.6	17.8	50	80	110	60	80
Meikle Bin	29	84.8	2.20	11.8	14.0	50	90	100	50	90
South Ridge Line	40	75.3	2.48	15.7	20.9	50	70	110	60	70
Stirling Castle	36	80.6	2.76	16.6	20.6	50	80	110	60	80
White House	40	89.5	1.94	12.3	13.8	70	90	110	40	80
All	346	79.3	0.791	14.7	18.6	50	80	110	60	70

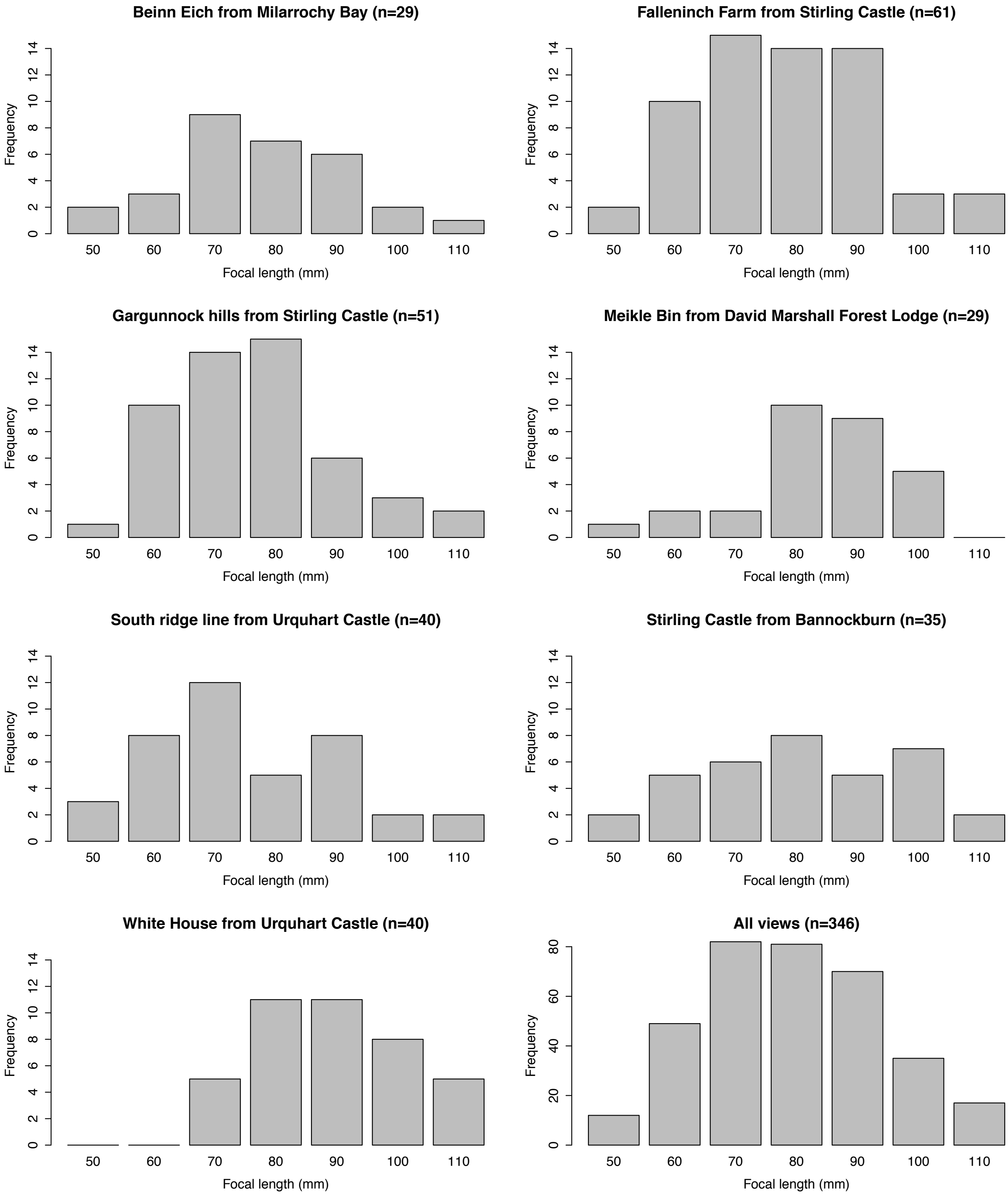

Figure 3. The distribution of photographic focal lengths selected by respondents as providing the most realistic representation of scale and distance in the natural landscape for selected viewpoints (n≥25) and the full aggregated sample.

4.3.3 The observed differences in the number of participants selecting each focal length was statistically significant for the aggregated responses from all views (Chi-Square Goodness-of-Fit test: $X^2_{(6,\ n=346)} = 104.0$, $p<0.0005$). A post-hoc examination of the standardised residuals from the Chi-Squared test revealed that the frequency of respondents selecting the 50mm, 100mm and 110mm photographic images was statistically lower than expected (i.e. standardised residuals less than minus 2). This result was generally echoed for individual views (only those with n≥35 responses were considered such that the expected frequency for any one focal length was ≥5 as required for the Chi-squared test) with statistically significant differences in focal length frequencies observed for the views of Falleninch Farm from Stirling Castle, the Gargunnock Hills from Stirling Castle, the South Ridge Line from Urquhart Castle and the White House from Urquhart Castle. In all instances the frequency of respondents selecting the 50mm photograph was statistically lower than expected with the exception of the view of the South Ridge Line from Urquhart Castle. The observed focal length frequencies for the view of Stirling Castle from the Bannockburn Visitors Centre were not statistically different from those expected to occur by chance. The results from the Chi-square test are summarised in Table 5.

Table 5. Summary of Chi-Square Goodness-of-Fit tests performed on observed focal length frequencies for selected views and the full sample. Numerical underrepresentation and overrepresentation of focal lengths based on observed Chi-square standardised residuals.

View	n	df	Chi-squared	p-value	Underrepresented focal lengths	Overrepresented focal lengths
Falleninch Farm	61	6	23.8	0.001	50mm	70mm
Gargunnock Hills	51	6	27.4	<0.0005	50mm	70mm; 80mm
South Ridge Line	40	6	15.0	0.021		70mm
Stirling Castle	36	6	6.78	0.342		
White House	40	6	22.3	0.001	50mm; 60mm	80mm; 90mm
All	346	6	104.0	<0.0005	50mm; 100mm; 110mm	70mm; 80mm; 90mm

4.3.4 The mean of the selected focal lengths for the full sample and for individual views was estimated by fitting Gaussian cumulative distribution functions (CDFs) to the observed focal length choices of participants. In the interests of conservatism, only the shortest focal length considered to provide an acceptable representation of landscape scale by the participant was used in calculation of the CDFs. The associated statistics are provided in Table 6. The mean (±2 standard errors (SE)) focal length for the full sample was 79.3mm (±1.58mm) with a standard deviation (StDev) and coefficient of variation (CoefVar) of 14.7mm and 18.6%. The median and modal focal lengths were 80mm and 70mm respectively. The interpretation of the CDF for the full sample indicates that 50% of participants in the study were of the opinion that the photographs taken at focal lengths of less than 79.3mm understated the scale and distance to the focal points.

4.3.5 It is noticeable that the mean focal length preference of respondents varied between viewpoints and individual views from 75.3mm (±4.96mm) for the view of the South Ridge Line from Bannockburn Heritage Centre to 89.5mm (±3.88mm) for the view of the White House from Urquhart Castle. The variability in the participants' focal length preferences was also variable between views with the StDev and CoefVar ranging from 11.8mm (14.0%) for the view of Meikle Bin from the David Marshall Forest Lodge to 16.6mm (20.6%) for the view of Stirling Castle from Bannockburn. This implies there was more of a consensus as to the focal length that provided the most realistic representation of those views such as Meikle Bin from the David Marshall Forest Lodge and the White House from Urquhart Castle than for Stirling Castle from the Bannockburn Heritage Centre or the South Ridge Line from Urquhart Castle. This variability at least in part likely reflects differences in the collective ability of participants to make judgements about scale and distance in the different landscape contexts used in the study.

4.4 The effect of focal point distance

4.4.1 The current visualisation standards published by The Highland Council stipulate that applicants must submit single frame printed images at a focal length of 70mm for distances up to 1.5km from the nearest turbine and 75mm for distances exceeding 1.5km. The principal that the focal length required to illustrate a specific focal point at the correct scale and distance in the landscape varies with distance was tested by examining the observed focal length preferences elicited from the participants as a function of the distance to the focal points in each landscape view. The responses were grouped for distances up to 1.5km, 1.5-5km, 5-10km, 10-15km, 15-25km and 25-50km to the focal point. The results are presented in Figure 4 as boxplots.

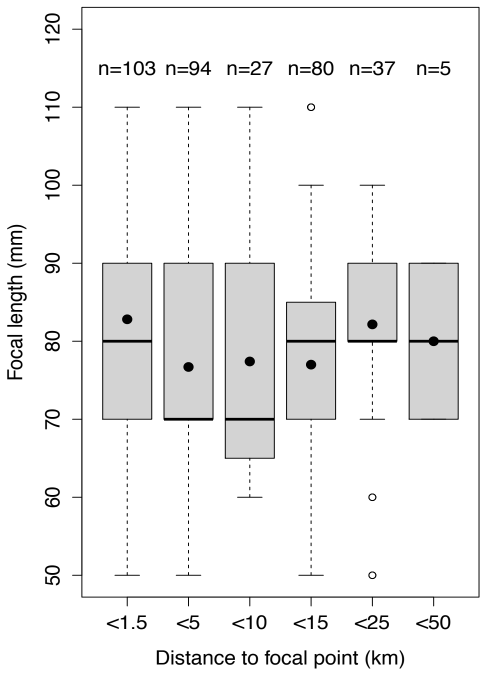

Figure 4. Focal length preferences as a function of distance to the focal point. The boxplots respectively (from bottom to top) show lowest outliers (less than 2/3 of lower quartile), minimum, lower quartile, median, mean (solid circle), upper quartile, maximum and upper outliers (more than 2/3 of upper quartile).

4.4.2 The results presented in Figure 4 do not show a clear systematic relationship between distance to the focal point and the focal length considered to provide the most realistic representation of the scale and distance to the focal point. It was anticipated that the participants' preferred focal length would increase as the distance to the focal point (or area) increased. However, the results show that focal length preferences for views over the shortest distances considered in the study (<1.5km) were comparable to those for very long distances (>25km).

4.4.3 Interestingly, the view of the White House from Urquhart Castle had highest mean focal length preference (89.5mm ±3.88) but one of the shortest distances to the focal point at approximately 1.40km. Similar results were observed for the view of Stirling Castle from Bannockburn in spite of the fact the distance to the focal point was only 3.36km. There is some indication that the focal length providing the most realistic representation of scale and distance to the focal point increased from approximately 75mm over intermediate (1.5-15km) distances to approximately 80mm at longer (25 km) distances. However, the results are too inclusive to permit any firm conclusions to be drawn.

4.5 Determinants of focal length preference

4.5.1 The factors that influenced the participants' choice of focal length were investigated using an interval regression model. Interval regression is a form of linear regression where only the intervals where the observations (here the participants' selected focal lengths) fall are visible of the otherwise continuous variable (c.f. Rabinowitz et al., 1995) and was appropriate in our case as we only provided respondents with photographs at discrete intervals representing what is in fact a continuous variable. In other words, if a participant were to select a focal length of 70mm, we actually know that their 'true' preference would lie somewhere in the interval between 70mm and 80mm.

4.5.2 The interval regression model was fitted in R using the ‘intReg’ package. Initially a full model was fitted for all responses using distance to the focal point as well as the sex, age and eyesight of the participants as predictors. Non-significant predictors at a 90% significance level were subsequently removed in a stepwise fashion until only significant predictors remained in the reduced model.

4.5.3 The interval regression model revealed that of the various explanatory variables used only the participant’s age was found to be a significant predictor of focal length preference (p=0.0006). None of the other variables were found to have a significant effect on focal length preference, including distance to the focal point. The estimated coefficient for the effect of age on focal length indicates that older participants tended to choose longer focal lengths than younger participants although the size of the effect was small. The results of the interval regression model are summarised in Table 6.

Table 6. The results of the interval regression model used to determine the factors affecting the participants’ choice of focal length. Only the reduced model is shown retaining variables significant at p=0.10 or less.

	Coefficient	Standard Error	t-value	Pr(>| t |)
(Intercept)	77.8449	2.0860	37.318	< 2e-16 ***
AGE	0.1523	0.0441	3.454	0.000623 ***
Sigma	8.2582	0.4638	17.804	< 2e-16 ***
Log-Likelihood: -627.0317				
Degrees of freedom = 343				

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

4.6 Interviewer bias

4.6.1 A single interviewer from the University of Stirling administered the questionnaire survey used in this study at all viewpoints. To test for possible interviewer bias in the responses obtained from the main survey we undertook a repeat survey for the view of Dumyat from Stirling Castle using five independent interviewers. These interviews were conducted over the same time period as the main survey but on different days to minimise the possibility that the same participants were sampled twice. The same photography and survey method was used for both sets of interviews. The results of the comparison are shown in Figure 5.

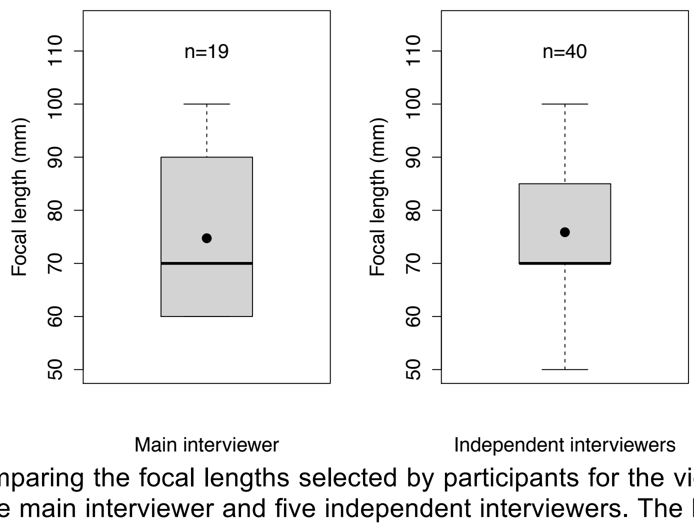

Figure 5. Boxplots comparing the focal lengths selected by participants for the view of Dumyat from Stirling castle Esplanade by the main interviewer and five independent interviewers. The boxplots respectively (from bottom to top) show lower outliers (less than 2/3 of lower quartile), minimum, lower quartile, median, mean (solid circle), upper quartile, maximum and upper outliers (more than 2/3 of upper quartile).

4.6.2 The comparisons in Figure 5 show near identical results were obtained using different interviewers. The observed mean for the main interviewer used in the survey was 74.7mm versus 75.9mm for the collated results from 5 independent interviewers. In addition, the interviewers also returned identical medians of 70mm. A comparison of the two focal length distributions elicited by the interviews showed no statistically significant differences (Mann-Whitney's *U* test: U = 350, p = 0.618). This is strong evidence that the survey design was robust.

5 DISCUSSION AND IMPLICATIONS

5.1 Focal length and photographic realism

5.1.1 The main aim of this study was to identify what focal length(s) provides the most realistic representation of scale and distance in photographic images of landscapes. The results obtained are intriguing and clearly have important implications for the visualisation of wind energy and other large-scale developments. The majority of participants interviewed during the study were of the opinion that a focal length of between 70mm and 80mm provided the most realistic representation of the scale and distance to the selected focal points in each landscape. The mean and median focal lengths for the individual views and the aggregated sample were ≥70mm in all cases with a mean and median for the aggregated sample of 79.3 (±1.58mm) and 80mm respectively. Similarly, the modal focal length of the aggregated sample and for individuals views (for n>5) was also 70mm or greater.

5.1.2 These results suggest that a photographic image at a focal length of 50mm will, in the landscape settings considered in this study, more often than not underrepresent the scale and distance to the focal point of interest. In other words, a 50mm image will tend to make features within the landscape appear too small and too far away relative to how they appear in the real landscape. This observation held true irrespective of the distance to the focal point under observation. Indeed, we found that even for distances to the focal point of between 0.18km and 1.5km the mean of the focal lengths selected by participants was still >70mm. These findings suggest for most views the current use of a 50mm focal length for VIA is far too conservative and will generally understate the visual impact of a development in the landscape.

5.1.3 The results of this study suggest that a focal length of between 70mm and 80mm generally provides the most realistic representation of landscape scale and depth although photographic perceptions of scale and distance clearly vary somewhat between individuals. Clearly, there is no single focal length that would be acceptable to all individuals, but the results do show more plainly what focal length(s) would be considered acceptable by the largest proportion of the public. The results for the full sample show that marginally more participants selected the 70mm focal length than any other although the mean focal length was somewhat higher at 79.3 mm (±1.58mm). The estimated modal focal length was also more conservative than the mean for 6 of the 8 views with a sample size greater than 25. But while the modal focal length of the aggregated sample was 70mm, it is notable that more than 50% of respondents were of the opinion that the most appropriate focal length was greater than 70mm.

5.1.4 The mean is perhaps a more appropriate guide as to the focal length most generally appropriate for production of visualisations. The observed mean focal length for the full sample was 79.3mm (±1.58mm), but obviously for technical and practical reasons it would not be feasible to stipulate such a precise focal length for visualisations. In the pilot study we often observed that participants found it difficult to distinguish between photographs where the difference in focal length was only 5mm. Thus our results suggest a photograph at a focal length of 75mm would be that considered by the largest proportion of the public as providing the most realistic representation of scale and depth – at least for the landscape types and viewing distances considered in this study. This is also consistent with the current Highland Council Standards that stipulate the use of a 75mm focal length for distances over 1.5km to the proposed development. Further, a focal length of 75mm is arguably still relatively conservative given the skew in the distribution of focal length preferences towards the longer telephoto end of the range.

5.1.5 The Highland Council Standards specify that a focal length of 70mm should be used for distances up to 1.5km to the development. The main purpose of the study was not to investigate the effect of distance on focal length preference but nevertheless we anticipated that it might have some effect, particularly for the more distant views. However, we did not find any clear evidence that the focal length providing the most realistic representation of scale in the landscape varied as a function of distance to the focal point. Consequently, on this basis it is difficult to make any firm recommendations on the appropriate focal length for a given distance to the proposed development. In light of this, and in the interests of simplicity for applicants, planning officials and the public, it might be preferable to specify a single focal length of 75mm for all VIA visualisations irrespective of distance at least until such time that the effect of distance is more clearly understood. This could obviously be accompanied by a stipulation that additional images at a shorter or longer focal length may be required for specific views at the discretion of the planning authority. The extent to which the appropriate choice of focal length used for photography in VIA depends on the distance to the development in the landscape certainly merits further investigation.

5.2 Factors influencing landscape depth perception

5.2.1 The perception of depth in landscapes and the pictorial representations of landscapes is a somewhat complex function of a number of visual cues such as interposition, relative height and size, linear perspective, texture and aerial perspective (Coren et al., 1994). We observed marked variability in individual-specific perceptions of depth in this study. For almost all of the views considered, the focal length selected by participants as that providing the most realistic representation of the scale and distance ranged between 50mm and 110mm. Similar variability was also observed during the initial field tests and the later pilot study.

5.2.2 It is important to recognise that as the focal length of the image changes, the presence and relative importance of depth cues is also likely to change as the field of view decreases. The changing field of view can have a significant effect on the presence and effect of cues such as interposition and relative height and size (Kraft and Green, 1989). Thus, the means by which an individual perceives depth in an image taken at a 50mm focal length is likely to be different from how depth might be perceived in the same image taken at a longer telephoto focal length of say 70mm or 90 mm. Further, the availability of depth cues also varies between landscapes. For instance, townscapes will typically contain more visual depth cues than a flat open vista of moorland environment where common cues such as interposition and linear perceptive are likely to be absent. The purpose of this study was primarily to field test current visualisation standards and not to explicitly investigate why depth perception varies between individuals and landscapes. This would require a more experimental approach than adopted here but this warrants further investigation in the future.

5.2.3 There is a further practical implication of this natural variability in individual-specific perceptions of depth in landscapes and landscape photographs. It is unlikely to be the case that all individuals involved in the assessment of the visual impact of a proposed wind energy development are likely to agree on the appropriateness of the visualisations submitted as part of the Environmental Statement. Some may be of the opinion that a selected focal length overemphasises the distance to a proposed development in the landscape, while others might be of the contrary opinion. This is to be expected as indicated by the lack of a clear consensus observed during this study. The objective therefore must be to use a focal length for VIA that could be expected to provide an acceptable representation of the scale and distance to a development for the 'average' individual (but with appropriate verification). On the basis of this study, a 75mm focal length would seem to be the most appropriate choice.

5.2.4 We observed that the focal length perceived to provide the most accurate representation of scale and distance to the focal point increased with the age of the participant. The effect was slight, but statistically significant. It is unlikely that age *per se* influences depth perception. It is possible however this might reflect the effect of deteriorating eyesight on the depth perception. It is common to experience a progressive and diminishing ability to focus on near objects with increasing age (a condition termed presbyopia). Individuals with presbyopia generally have to view an object at a greater distance in order to focus. In the context of this study, individuals with presbyopia whose eyesight was not adequately corrected to normal might have tended towards longer focal lengths to compensate for the increased viewing distance. This finding might have implications for VIA where visualisations need to be viewed at fixed distances to achieve correct perspective.

5.3 **Correct viewing of visualisations**

5.3.1 This study also uncovered some important considerations for the viewing of photographs for VIA. Firstly, it is apparent that the size of the printed image size is of utmost importance. Currently, The Highland Council Standards specify that images should be printed on an A3 page with a vertical height of 240mm and a horizontal width of 360mm to preserve the 3:2 proportions of the single frame image. The recommended binocular viewing distance (from the eye) for an image of this size is about 500mm (approximately the diagonal of an A3 page) (The Highland Council, 2010).

5.3.2 In this study, we were very specific with participants that the images should be held at a '*comfortable'* viewing distance (but not necessarily at 'arm's length'). It was noticeable that the natural viewing distance for most respondents was instinctively about 500mm for the A3 images (but note this was generally short of an arm's length for most participants). However, because perceptions of depth and scale are proportional to the viewing distance, if an image is held too close to (or too far away from) the eye then the effect will be to make the focal point(s) in the image appear larger (or smaller) than observed in the landscape.

5.3.3 It is therefore important that clear instruction is provided as to how the images should be viewed. We fully endorse the original recommendations made in University of Newcastle (2002) on viewing distance in regards to "*what is comfortable and natural for the viewer should dictate the technical detail and not vice versa*". It is our view that most respondents would be required to hold a 50mm focal length image at an unnaturally close viewing distance before the image would provide an adequate representation of the actual scale and depth observed in the landscape. The fact that the panoramic images constructed from multiple images which are included in Environmental Statements for wind energy developments are often not viewed *in-situ* means the provision of viewing instructions is all the more important as there is no means of verifying the realism of the visualisation.

5.3.4 There is an unavoidable trade-off between the focal length of a photograph and the field of view. Images taken at a longer focal length have a narrower vertical and horizontal angle of view and one consequence of this is the loss of foreground detail. In the initial field tests for this study we observed that the choice of focal length made by some participants was influenced not only by the relative scale of the focal point in the landscape but also by other cues, particularly the extent of foreground visible in the image. Such effects are likely to confuse the assessment of visual impact where the primary concern is the scale of a proposed development rather than the impact on the wider landscape. We therefore recommend that guidance be provided when viewing single frame and panoramic visualisations in the field such that individuals are instructed to view the images in a natural and comfortable manner such that any immediate foreground visible in the landscape but not in the photograph is obscured from the observer's view by the image itself.

6 SUMMARY AND RECOMMENDATIONS

6.1.1 The results of this study demonstrate that a single frame A3 photographic image taken at a focal length of between 70mm and 80mm generally provides the most realistic representation of the scale and distance to focal points over distances of approximately 0.2-43km.

6.1.2 The focal length that would be considered by most individuals to provide an acceptable perspective of the scale and distance in a real landscape is likely to be approximately 75mm in most circumstances.

6.1.3 This finding is inconsistent with the current indications made in SNH (2006) that a focal length of 50mm should be used as the base standard but is in broad agreement with the current Highland Council Standards (Highland Council, 2010).

6.1.4 The study did not find a systematic relationship between distance to the focal point in the image and the focal length perceived to provide the most realistic representation of the scale and distance to that focal point. This is an issue that warrants further detailed investigation.

6.1.5 On this basis, it is recommended that single frame photographs included in Environmental Statements for VIA be produced using a 75mm focal length irrespective of distance to the proposed development unless the landscape context clearly dictates otherwise. The inclusion of a photograph at a 50mm focal length is not seen as necessary.

6.1.6 It is recommended that the photographs for VIA are viewed at a natural and comfortable distance and held in such a manner that image itself obscures any foreground detail visible in the landscape that is not within the vertical field of view of the image.

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APPENDIX I

Stirling Castle - Queen's Garden

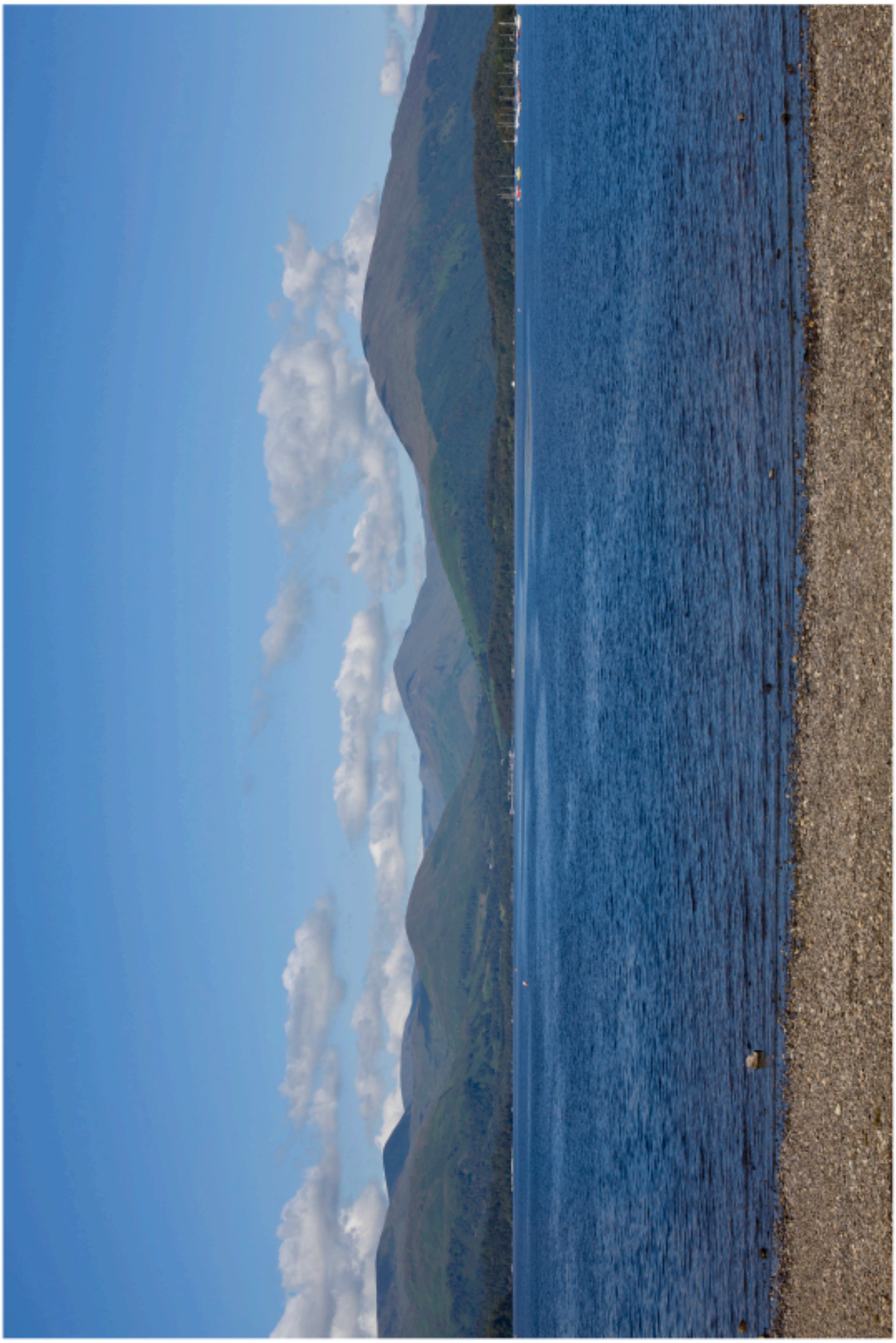
50mm focal length

Bannockburn - North side of Circle

50mm focal length

Bannockburn - South side of Circle

50mm focal length



Milarrochy Bay - Beach side of West Highland Way in front of Park Ranger Station

50mm focal length

David Marshall Forest Lodge - Cafe viewpoint telescope - Meikle Bin 50mm focal length

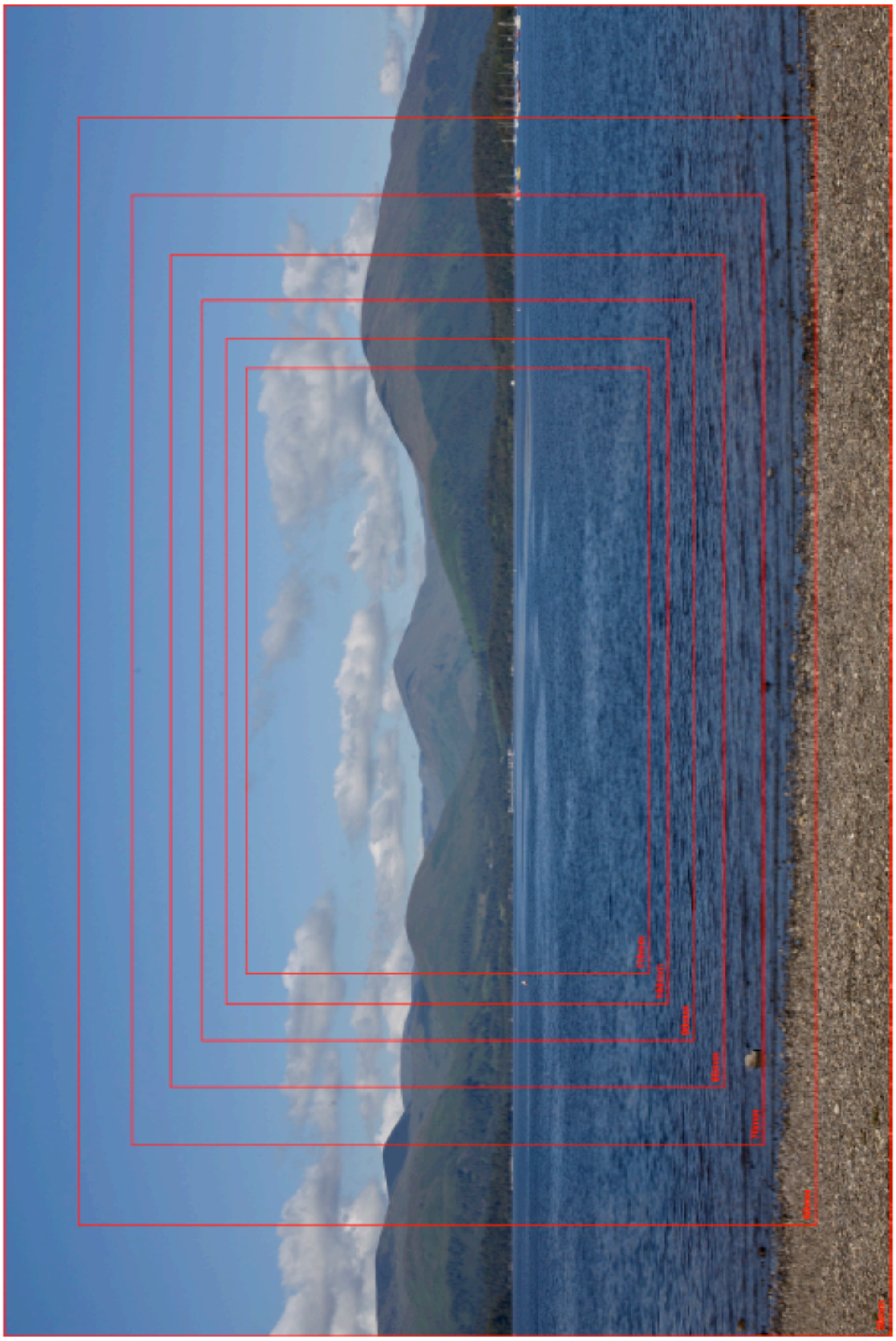
Urquhart Castle - Entrance to castle precinct

50mm focal length

Urquhart Castle - SW Tower view from ruin

50mm focal length

APPENDIX II



Focal length re-calibration from a 50mm image