USE OF X-RAYS AND QGIS® SOFTWARE TO EVALUATE DETERIORATED WOOD IN MARINE ENVIRONMENTS

Tarcila Rosa da Silva Lins[1*], Marks Melo Moura[2], Ana Claudia de Paula Müller[3], Paulo da Cunha Lana[4], Márcio Pereira da Rocha[5]

[1*]Universidade Federal do Paraná, Programa de Pós-Graduação em Engenharia Florestal, Curitiba, Paraná, Brazil – tarcila.lins@hotmail.com
[2]Universidade Federal do Paraná, Programa de Pós-Graduação em Engenharia Florestal, Curitiba, Paraná, Brazil - marksmoura@yahoo.com.br
[3]Coordenação de Meio Ambiente e Desenvolvimento Sustentável/ IPARDES - Instituto Paranaense de Desenvolvimento Econômico e Social, Curitiba, Paraná, Brazil - anapmuler@gmail.com
[4]Universidade Federal do Paraná, Centro de Estudos do Mar , Pontal do Paraná, Paraná, Brasil - lana@ufpr.br
[5]Universidade Federal do Paraná, Departamento de Engenharia e Tecnologia Florestal, Curitiba, Paraná, Brazil - mprocha01@gmail.com

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Resumo

Uso de raios-X e do software QGIS® para avaliar madeira deteriorada em ambiente marinho. O objetivo deste trabalho foi propor uma metodologia não destrutiva para identificar e quantificar os danos causados por brocas marinhas em peças de madeira. Um corpo de prova esteve submerso em ambiente estuarino durante cento e vinte dias. Após esse período, a amostra foi removida e levada para o laboratório. A técnica de radiografia foi utilizada para detectar e avaliar o ataque por brocas marinhas. Dois métodos de avaliação foram aplicados a partir das imagens desse corpo de prova, para posterior comparação. A primeira avaliação foi realizada utilizando como ferramenta o programa de geoprocessamento QGIS® para o tratamento das imagens, que possibilitou a identificação e a quantificação dos danos (em cm²). A segunda avaliação seguiu o método indicado na EN 275 (1992), que sugere uma avaliação visual, a partir das imagens de raios-x, classificadas de acordo com um gabarito fornecido na norma. Observou-se que, apesar do método utilizando o tratamento de imagens pelo QGIS® ser uma estimativa, ele tem a vantagem de fornecer um resultado numérico, em contrapartida à análise visual que não é tão precisa devido à sua subjetividade. Além disso, o tratamento das imagens possibilitou uma boa visualização dos danos na amostra. Sugere-se que o QGIS pode ser utilizado como um complemento do método proposto pela EN 275 (1992).
Palavras-chave: Área de infestação, brocas marinhas, método não-destrutivo, moluscos, crustáceos.

Abstract

The objective of this work was to propose a nondestructive method to identify and quantify the damage caused by marine borers in wood structures. First, a test specimen was submerged in an estuarine environment for 120 days. Radiography was then applied to detect and evaluate the attack by marine borers. Two methods of evaluation were performed with the images to compare them. The first assessment was carried out using the QGIS® geoprocessing program for the treatment of images as a tool, which made it possible to identify and quantify the damage (in cm²). The second evaluation followed the method indicated in EN 275 (1992), which suggests a visual assessment, based on X-ray images, classified according to a template provided in the standard. Although the method using the image treatment by QGIS® is an estimate, it has the advantage of providing a numerical result, in contrast to the visual analysis, which is not as accurate due to its subjectivity. Besides this, the treatment of the images allowed good visualization of the damage to the specimen. The findings indicated that QGIS® can be used as a complement to the method proposed by EN 275 (1992).
Keywords: infested area, marine borers, nondestructive method, mollusks, crustaceans.

INTRODUCTION

Wood is commonly used to support structures in marine environments due to the ease of manufacturing/constructing and maintaining vessels, port structures and infrastructure in general (Borges, 2014). Despite these advantages, wood suffers from low durability when submerged in brackish and marine waters because of its susceptibility to xylophagous organisms such as marine borers. These borers are divided into two large groups: mollusks and crustaceans (Kollmann & Côté, 1968). Within the group of mollusks, wood-boring bivalves of the families Teredinidae and Pholadidade are widely distributed both in marine and estuarine environments (Boyle & Turner, 1976). The same authors reported that the genera *Teredo* sp. and *Bankia* sp. (Mollusca: Teredinidae) cause particularly severe damage due to their intense action of destroying wood in marine environments. These mollusks penetrate the wood at the end of their larval stage and begin boring in the adult stage. Besides opening of boreholes inside the wood, the mollusks are also growing (Müller & Lana, 2004). Infestation is rarely noticeable on the wood surface since the holes are small, but the action of the borers can cause

the structure to break or collapse. The damage caused by marine borers is enormous, especially since it is difficult to identify infested structures and vessels, particularly in the initial phase.

One of the techniques used to identify wood biodeterioration is X-ray analysis, which detects damage caused by animals such as termites (Himmi *et al*., 2016; Wedvik *et al*., 2016). This analysis detects insect nests and wood-rotting fungi, as well as measures the contaminated or lost area (Alfieri & Correa, 2017). The standard that is currently used to measure such attacks is EN 275 (1992), which specifies how to evaluate experimental results and to identify damage caused by attacks of mollusks and crustaceans. The standard suggests applying radiography and subsequent visual analysis of the specimen using a classification system, adopting a scale from 0 (structure with no signs of attack) to 4 (structure completely compromised).

This kind of study proposed by EN 275 (1992) is limited, since the results are only based on visual analysis and do not precisely quantify the damaged wood area. Because it is based on the individual interpretation of each evaluator, this method is subjective, since the results of visual classifications cannot necessarily be replicated by different observers. Moreover, because radiographs are in black and white, the resolution of visual analysis can be impaired by similar pixel colors, leading to misclassification.

Nondestructive or *in situ* methods can be used to deal with these limitations, especially in the case of fixed structures, such as piers, where partial removal for analysis is not feasible. Also, in cases of infestation of mobile structures such as vessels, radiography can identify perforated parts without disassembling the hull to assess the damage. However, this method may not be efficient for detecting infestation in some cases, such as the early stages of attack, when wood may only have caused a few small holes, making diagnosis difficult. This limitation justifies the use of a new method that includes image treatment based on differences in the pixel tones to quantify the mass loss and consequent structural deterioration.

Our hypothesis was that the use of radiographs obtained with portable equipment, submitted to an image treatment, can be an adequate tool for making decisions on actions to control damage to marine structures and/or repair them. Thus, the objective of this work was to test the effectiveness of a nondestructive method to quantify the area of wood damaged by the action of marine borers and to compare this method with that proposed by the standard EN 275 (1992).

MATERIALS AND METHODS

The test specimen evaluated in this study is part of a more comprehensive experiment carried out in the lower third of the Guaraguaçu River (-25.588541 N; -48.482628 W), where action of marine borers were previously detected. It had remained submerged for120 days. As the focus of this paper is to present the application of a new method, only one specimen was used. The specimen was composed of *Pinus taeda* L., treated with burnt oil applied by the hot-cold bath method, with density of 0.5136 g/cm³ and initial dimensions of 4.5 x 4.5 x 30 cm. Since the method proposed here uses the four largest faces of the test specimen, the initial area used was 135 cm² (4.5 x 30 cm), which corresponds to 100%.

After being removed from the marine environment, the specimen was radiographed according to EN 275 (1992), using a portable X-ray machine (Blazer-X Vidisco/ XRS-3/ 270 kV of power) (Curitiba, Brazil) and a scanner (ScanView CR-S) (Curitiba, Brazil). Ray intensity was adjusted according to the level of damage of the specimen. Thus, the pulse intensity was determined by trial and error until the best image was obtained. For the specimen used in this study, the ideal intensity was 13 pulses.

The four largest sides of the specimen were radiographed. From these radiographs, it was possible to perform the image processing steps. Each side of the specimen was processed individually, following steps 2, 3, 4 and 5 of Figure 1, reaching a value in cm² that was transformed into a percentage (%). After carrying out the process for each side of the specimen, the average of the four sides was computed to estimate the value of the damaged wood area. This procedure was performed on the four sides to ensure that the maximum number of boreholes was visualized in the specimen.
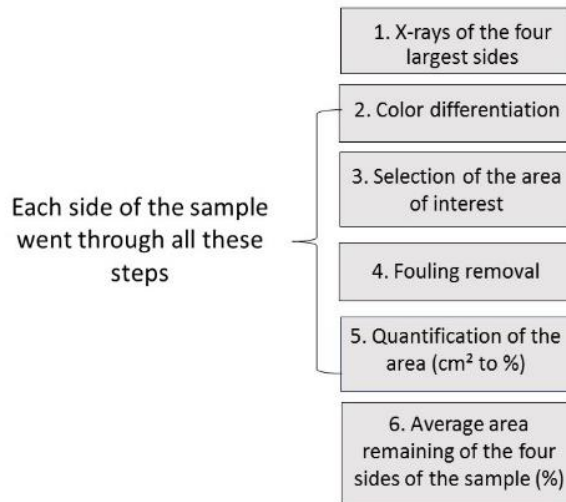
Figure 1. Method used to obtain an estimated value of the damaged wood area in the specimen.
Figura 1. Metodologia utilizada para obter um valor estimado da área de madeira danificada na amostra.

As the process was the same for the four sides of the specimen, the images presented below show all the steps performed for one side of the specimen, to illustrate what was done without being repetitive.

Image processing using QGIS®

The images obtained by the radiographs were examined using the free software QGIS® version 3.8 (Zanzibar) to determine the damaged area of the original specimen. For this, a template was created in the software using the original dimensions (Figure 2) of the specimen, which was added with each radiographic image. This process is essential because the X-ray images do not have a scale, and through the layer overlay process and the template with the referenced points, it was possible to add a scale.
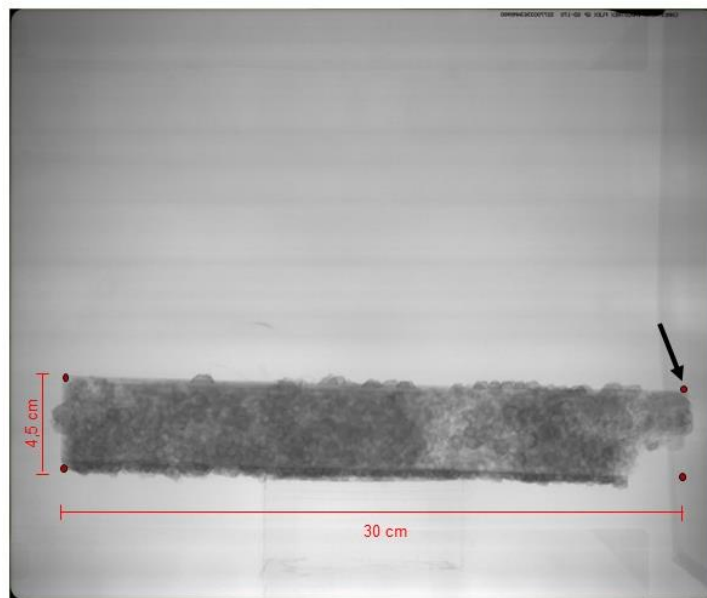

Figure 2. Addition of points in the initial dimensions of the largest sides of the specimen (4.5 x 30 cm) that had the function of scale, which provides essential information for the processing of images.
Figura 2. Adição dos pontos nas dimensões iniciais dos lados maiores do corpo de prova (4,5 x 30 cm) que tiveram a função de escala, uma informação essencial para o processamento das imagens.

For this, an open-source supervised classification plugin, called Semi-Automatic Classification Plugin (SCP), was used. Then, the scaled images were inserted into the software and subjected to a grouping analysis in which the pixels were classified into color scales, creating layers by grouping the pixels having equal tones (Figure 3). The arrow in Figure 3b indicates a region damaged by the organisms. The red rectangle represents the remaining area of wood, while the colors green, blue and purple, along with the portion of red at the top of the image

correspond to the plate used to capture the X-ray image, which was behind the specimen. The pixel layers that did not correspond to the remaining wood were disregarded in the evaluation.
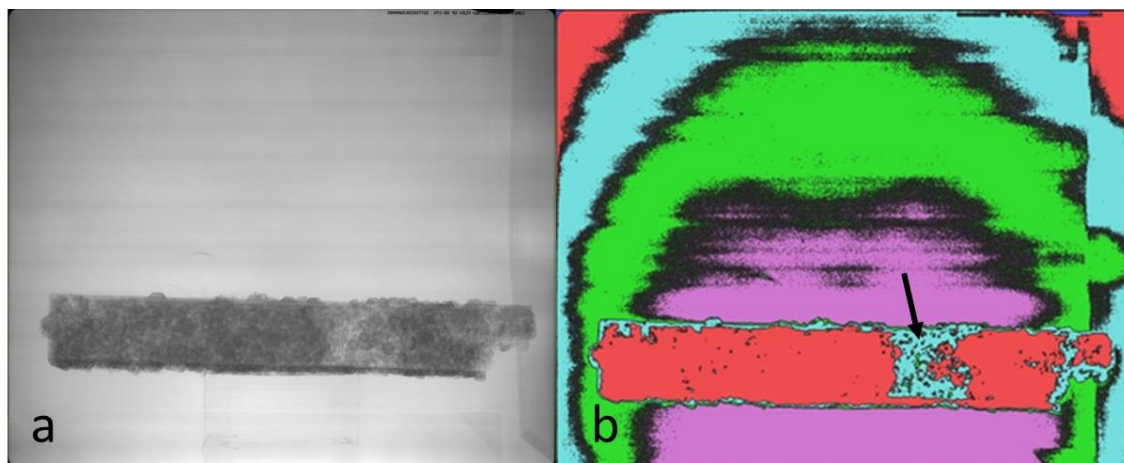

Figure 3. Definition of the color layers of the specimen shown by the X-ray image after the attack by marine borers, where each color represents a grouping of pixels in the QGIS® software.
Figura 3. Definição das camadas de cores à partir da radiografia do corpo de prova após o ataque de brocas marinhas, onde cada cor representa um agrupamento de pixels no software QGIS®.

After isolating the area corresponding to the specimen, the remaining area of the wood layer was quantified in cm², accounting for the polygon areas obtained in the previous process. This result was transformed into percentage to standardize the units and facilitate comparison with the results of the visual classification method. The same procedure was performed for each side of the specimen, and the final result of the damaged area was calculated as the average of the four radiographed sides.

Visual classification of radiographs

The visual classification of radiographs was carried out following EN 275 (1992). For this, five evaluators participated in the study after brief previous training. The evaluators were instructed to categorize the radiographed images of the four largest sides of the specimen according to Table 1. To prevent any kind of influence, each evaluator performed the analysis individually, without the presence of the others.

Table 1. Rating system for shipworm attacks according to EN 275 (1992).
Tabela 1. Sistema de classificação dos ataques por moluscos que perfuram a madeira de acordo com a EN 275 (1992).

Rating	Classification	Condition and appearance of test specimen
0	No attack	No sign of attack
1	Light attack	Single or a few scattered tunnels covering not more than 15% of the specimen according to the X-ray image.
2	Moderate attack	Tunnels covering not more than about 25% of the specimen according to the X-ray image.
3	Severe attack	Tunnels covering between 25 and 50% of the specimen according to the X-ray image.
4	Failure	Tunnels covering more than 50% of the area of the specimen according to the X-ray image.

Source: EN 275 (1992)

To compare the methods, the radiographs presented to the evaluators were the same ones that later underwent image processing using QGIS®.

RESULTS

From the radiographic image (Figure 4a), we obtained an image that helped to classify the tone of each group of pixels. This step facilitated the visualization of different layers in the specimen. After identifying the color that corresponded to the remaining portion of the wood, the other layers were excluded from the image, leaving only the layer that corresponded to the specimen (Figure 4b) in brown and the damaged area indicated by a black arrow. However, the image still showed the presence of biological fouling, such as by algae, barnacles and other organisms. These organisms were identified by the ripples on the specimen surface, as shown by the yellow arrow in the image. Using the scale again, it was possible to delimit the area referring to the initial specimen with known dimensions (Figure 4c). Then, everything that was outside this area was deleted (otherwise, these biofouled areas would considerably increase the final image area calculated, which is not desirable. Figure 4d shows the final image obtained disregarding the portions that corresponded to the biological fouling.
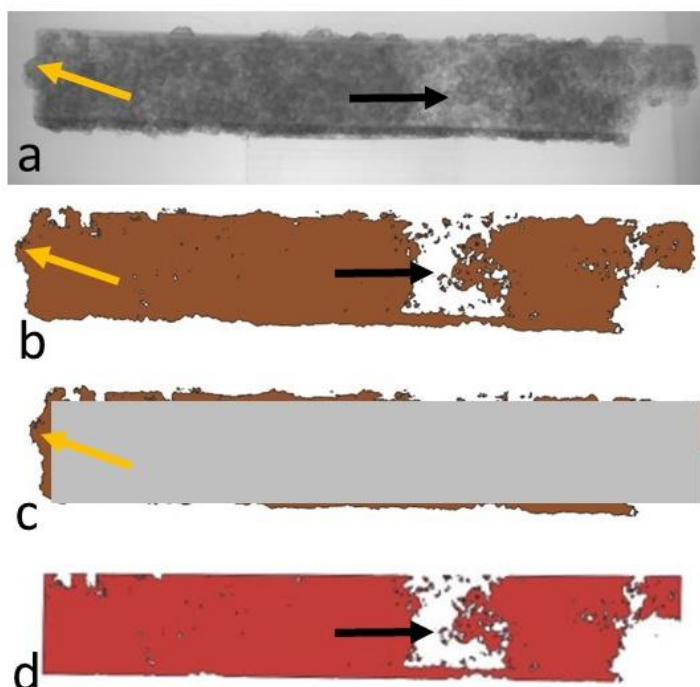

Figure 4. Steps of removing the layer of biological scale in the wood specimen. a: X-ray image of the specimen; b: Digital image after image processing; c: Creation of a polygon with the initial dimensions (4.5 x 30 cm); d: Final image of the specimen with its delimited dimensions, without biological incrustations. The black arrows indicate a damaged region and the yellow arrows indicate a region where the presence of biological scale is visible.

Figura 4. Etapas da remoção da camada de incrustações biológicas na amostra de madeira. a: Imagem de raios-x do corpo de prova; b: Imagem digital após o tratamento de imagem; c: criação de um polígono com as dimensões iniciais (4,5 x 30 cm); d: Imagem final do corpo de prova com as suas dimensões delimitadas, sem as incrustações biológicas. As setas pretas indicam uma região danificada e as setas amarelas indicam uma região onde se visualiza a presença de incrustações biológicas.

After the complete treatment of the images, it was possible to determine the remaining area in cm² for each face of the specimen. The image treatment allowed a remarkable visualization of the lost area concentrated on the right side, as well as its quantification. There was a considerable loss, which would compromise good performance in service due to risks of breakage or collapse.

Table 2 shows the results of the two methods proposed in this work, the visual method proposed by the standard EN 275 (1992), represented by the columns of the evaluators, and the quantification of the area using the method proposed here, which corresponds to the column "QGIS®".

Table 2. Classification of radiographic images by the visual evaluation method and percentages calculated by the QGIS® image treatment.

Tabela 2. Classificação das radiografias pelo método da avaliação visual e os percentuais calculados pelo tratamento de imagens com o QGIS®.

Side	Evaluator 1	Evaluator 2	Evaluator 3	Evaluator 4	Evaluator 5	QGIS®
1	Failure	Severe attack	Severe attack	Light attack	Light attack	Moderate attack
2	Failure	Severe attack	Severe attack	Light attack	Light attack	Severe attack
3	Severe attack	Failure	Light attack	Light attack	Light attack	Severe attack
4	Severe attack	Severe attack	Severe attack	Light attack	Light attack	Moderate attack

DISCUSSION

The difference between simple visual categorization and the more quantitative method presented here is clear. Table 2 shows differences when comparing the responses of the evaluators and the quantification with QGIS®, as can be seen in the classification given for "side 1" of the specimen, where all the evaluators overestimated the amount of damaged area. In all situations, there was at least one categorization that was very different from the others, which demonstrates the influence of subjectivity.

These results reaffirm the problem of conducting a study based only on visual analysis, as the evaluators have different opinions that directly influence the result. Besides this, other factors can interfere with the evaluators' interpretation, such as the difficulty in differentiating the elements present in the radiographs during image presentation, due to the presence of similar shades in the grayscale in the most damaged places in the specimen, despite the previous training. Oftentimes, biological fouling was mistaken for damage caused by marine borers, which made it difficult for observers to evaluate the damage.

Image processing using QGIS® avoids this error, since the pixel grouping is formed from the density of the radiographed material, that is, those with similar density will be in the same group of pixels, indicated by the same color. In damaged places where there is a loss of area in the specimen, it will have a lower density than the remaining wood areas, so it will be part of another group of pixels. Also, another advantage of working with the QGIS® method is that it enables obtaining a numerical value, without the need to work with a wide range of classifications as occurs with EN 275 (1992).

The method proposed in this study allows adequate visualization of the interior of wood specimens damaged by marine borers. In this sense, the method complements the standard EN 275 (1992), with refinement in the radiography treatment, facilitating the identification of infestation degree by loss of surface area, which is calculated systematically and is replicable by different observers. Although radiographs do not provide enough data to accurately quantify the damaged area, they are an important resource for nondestructive assessment of wood (Wedvik *et al.*, 2016). The combination of these images with other tools, as proposed for QGIS®, provides an alternative nondestructive method that can be used to evaluate the action of other xylophages, such as fungi and insects, since this method does not have a limitation, and can also be applied in the terrestrial environment.

The development of new nondestructive methods will bring advances to the analysis of biodeterioration of wood, which still needs to be modernized with the use of more advanced technologies since many main analyses are still based on visual assessment, as in wood-rot field experiments and accelerated testing of wood decay fungi, as well as those conducted in marine environments. The method using radiographs and QGIS® can be applied to other situations in urban environments, such as with furniture, artwork and the like. Nondestructive assessment techniques are always required when it is not possible to remove specimens for further analysis (Anthony, 2010). According to Wedvik *et al.* (2016), nondestructive methods are of great interest, for example, to evaluate historic architectural structures, since the wood cannot be damaged. Therefore, the method using QGIS® can be of interest to these professionals, since it would be possible to carry out the evaluation of this material without causing damage to the structure. Thus, the method is not restricted to marine structures and can be adapted to structures in any environment. In these cases, when changing the type of material evaluated, such as different species of wood, it will require calibrating the intensity of the rays applied by the equipment to obtain images with better resolution, since the density of the material will not be the same.

Using QGIS® is an attractive alternative to reduce the visualization subjectivity in the evaluation, since it shows or quantifies the lost area numerically, complementing the evaluation suggested by the standard with the information provided by the image. Furthermore, recent studies have used radiographs only to visualize an area occupied by the tunnels, but not to quantify them (Eriksen *et al.*, 2015; Eriksen *et al.*, 2017). Another positive

point of this method is its reliance on open-source software, so it can be used on a large scale without financial obstacles.

One of the challenges of maintaining wood structures is early identification of the existence and extent of damage. Technologies such as X-ray provide better images of the boreholes formed by xylophagous organisms (Himmi *et al.*, 2016). But since the radiographs of wood attacked by marine borers are evaluated subjectively, the results are less accurate compared to a method that quantifies the damage, since visual analysis does not provide an estimate of the extent of the damaged area. Although QGIS® was originally developed for use in geoprocessing, its application to improve visualization of the attacked area in the wood specimen proved to be effective, since it differentiated the elements of the image in different colors, facilitating the identification of damage. This possibility of visualizing the damaged area can be useful to avoid accidents involving structures located in marine environments, since the damage caused by shipworms can barely be detected by the naked eye, especially in the early stages.

The use of portable equipment allows *in situ* examination of the structure, providing potential benefits to the engineering field (Wedvik *et al.*, 2016). Moreover, QGIS® image processing provides results quickly, facilitating decision-making for repair or replacement of affected structures. The method can also be used for preventive purposes, with periodic radiography of structures to monitor their conservation status. As a result, more accurate decisions can be made about replacing damaged areas, preventing them from becoming dangerous for use, reducing risks to people's safety and preventing other damage to property.

CONCLUSION

- The method using QGIS® proposed in this work provides good quantification of the degree of damage caused by marine borers. Thus the method can have practical application to prevent failure of wood structures located in these environments, by the earlier identification of the damage, helping to make decisions on replacement or repair.
- The method can be used for evaluation complementary to that proposed by the EN 275 standard, since it allows drawing conclusions about the damages caused by marine borers, especially mollusks.
- The method is not limited to the marine environment; it can be used in terrestrial environments to assess the damage caused by other xylophages, such as fungi and insects, provided the necessary adjustments are made.

ACKNOWLEDGEMENTS

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